Clarence River Floodplain Prioritisation Study

WRL TR 2020/06, May 2023

By A J Harrison, D S Rayner, T A Tucker, G Lumiatti,
P F Rahman, D M Gilbert and W C Glamore

UNSW Water Research Laboratory

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School of Civil and Environmental Engineering

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UNSW
Water Research Laboratory

www.wrl.unsw.edu.au
110 King St Manly Vale NSW 2093 Australia
Tel +61 (2) 8071 9800 ABN 57 195 873 179

Executive summary

ES.1 Preamble

The NSW Marine Estate Management Strategy (MEMS) (Marine Estate Management Authority, 2018) is a state wide strategy to protect and manage waterways, coastlines and estuaries over a ten year period (2018 – 2028). Initiative 1 of the Strategy is focused on improving water quality. Poor water quality specifically originating from diffuse agricultural runoff has been identified as one of the highest priority threats to the environmental assets within NSW estuaries (Fletcher and Fisk, 2017). Diffuse agricultural runoff was also identified as a significant threat to the social, cultural and economic benefits derived from the marine estate. Two major sources of poor water quality impacting the NSW marine estate result from diffuse acid sulfate soil (ASS) and low oxygen 'blackwater' runoff from coastal floodplains.

The Department of Primary Industries (DPI) – Fisheries commissioned the Coastal Floodplain Prioritisation Study with funding from the Marine Estate Management Strategy (MEMS) to identify priority locations across major NSW coastal floodplains where the greatest improvements in water quality can be achieved, through strategic management actions that reduce the impacts of ASS and blackwater runoff. This has been completed for the following seven (7) coastal floodplains in NSW:

- Tweed River floodplain;
- Richmond River floodplain;
- Clarence River floodplain;
- Macleay River floodplain;
- Hastings River floodplain;
- Manning River floodplain; and
- Shoalhaven River floodplain.

This report specifically provides an evidence-based assessment of 16 floodplain subcatchment drainage areas across the Clarence River floodplain. To determine how water quality from the Clarence River floodplain can be improved, subcatchments have been prioritised based on the risk they pose to the marine estate through the generation of poor water quality from ASS and blackwater runoff. Following the priority risk assessment, management options for short and long-term planning horizons have been suggested outlining potential strategies for each subcatchment to improve water quality outcomes. Importantly, this study identifies localised and site specific management responses targeted to sources of poor water quality considering key environmental, social, economic, cultural, and regulatory criteria. The outcomes from the study will provide an overview of floodplain processes, collate valuable datasets, provide potential management responses to address sources of poor water quality, and facilitate the streamlined implementation of actions to improve the health of the marine estate into the future.

ES.2 Background

Coastal floodplains in NSW have been extensively developed since the turn of the 20th century (Tulau, 2011). The expansion of urban and agricultural land uses has resulted in the construction of significant floodplain drainage systems to provide flood protection and improve agricultural productivity (Johnston et al., 2003a). Although floodplain drainage has improved agricultural productivity in some areas, the over drainage of coastal backswamps and wetland areas has resulted in the oxidation of acid sulfate soils (ASS), and the establishment of non-water tolerant vegetation in low-lying areas. This has contributed to the increased frequency and magnitude of poor water quality from ASS discharge and low oxygen blackwater runoff (Johnston et al., 2003b; Naylor et al., 1998; Tulau, 2011; Wong et al., 2011).

Coastal floodplains in NSW are often founded upon ASS which, when drained and oxidised, can discharge sulfuric acid and high concentrations of metal by-products into the receiving estuarine waters (Naylor et al., 1998). In areas affected by ASS, the combination of deep drainage channels and one-way floodgates increases ASS oxidation, creates acid reservoirs, and restricts potential buffering (or neutralisation) of acid by tidal waters (Johnston et al., 2003a; Stone et al., 1998). Acidic discharge causes adverse environmental, ecological and economic impacts to the floodplain and downstream estuarine receiving waters (Aaso, 2000). Impacts to aquatic ecology can be severe, including fish kills (Winberg and Heath, 2010) and oyster mortality (Dove, 2003a). Acid sulfate soils are widespread in the Clarence River floodplain and acid discharges have been responsible for fish kill events (Tulau, 2011).

Low oxygen blackwater is often generated on coastal floodplains following prolonged inundation during flood events. Blackwater is formed when floodplain inundation leads to the breakdown and decay of organic matter which consumes oxygen from the standing water column (Kerr et al., 2013). When flood levels in the river recede, low oxygen blackwater drains into the estuary, often further consuming oxygen from the river water (Eyre et al., 2006). Low oxygen blackwater impacts aquatic ecology, often resulting in large fish kill events (Moore, 2007). Although blackwater is a natural process, and blackwater runoff from floodplains has historically occurred (Wong et al., 2011), the construction of efficient floodplain drainage, combined with the establishment of non-water tolerant vegetation in low-lying floodplain areas, has increased the magnitude and frequency of blackwater runoff events (Wong et al., 2011).

Increasingly, the benefits of investing in coastal floodplain areas to reduce the discharge of acidic water, reduce the generation of low oxygen blackwater, and improve the overall water quality of the marine estate is being realised. The value of environmental assets within coastal floodplains are intrinsically linked with social, cultural, and economic benefits (Fletcher and Fisk, 2017). Improvements in floodplain management have resulted in a range of benefits from improved agricultural productivity, to improved water quality, establishment of wetland habitats, greater ecosystem services, and recovery of degraded estuarine environments. Understanding the areas that contribute the most to the generation of acid or blackwater on coastal floodplains is an important step to guide future investment and reduce the impact of poor water quality on the NSW marine estate.

ES.3 Study approach

The objective of the Coastal Floodplain Prioritisation Study was to develop a roadmap for the strategic management of ASS and blackwater runoff from NSW coastal floodplains to improve the water quality and overall health of the marine estate. This has been achieved through the development and application of an evidence based and data driven multi-criteria assessment involving:

- Application of a prioritisation methodology to rank subcatchment drainage areas within NSW coastal floodplains with regard to their contribution to acid and blackwater generation and the risk they pose to the health of the marine estate;
- A first-pass guide of management options for individual subcatchments outlining potential strategies for on-ground works to improve water quality; and
- Collation of catchment specific data relevant to the implementation of management options.

This approach enables the identification of high-priority subcatchments within coastal floodplain systems that can be targeted to improve water quality and guide floodplain management. The outcomes of the subcatchment prioritisation, development of management options and supporting information, provide an objective prioritised list of floodplain subcatchments with a roadmap on how to achieve water quality improvements across major NSW coastal floodplains. A detailed description of the multi-criteria assessment has been outlined in a separate background and methodology report by Rayner et al. (2023) that supplements this report.

The study approach features two (2) primary prioritisation methods that assess and rank floodplain subcatchments based on the risk they pose to the marine estate relating to poor water quality due to:

1. Discharge from acid sulfate soils; and
2. Generation of low oxygen ‘blackwater’.

These methods utilise an evidence based and data driven analysis which ranks subcatchments based on the risk they pose to an estuary in terms of the generation and export of poor quality water. The greatest potential benefit to the estuary can therefore be gained by reducing the sources of poor water quality from the subcatchments following the priority rank order. Figure ES-1 provides an overview of the prioritisation approach.

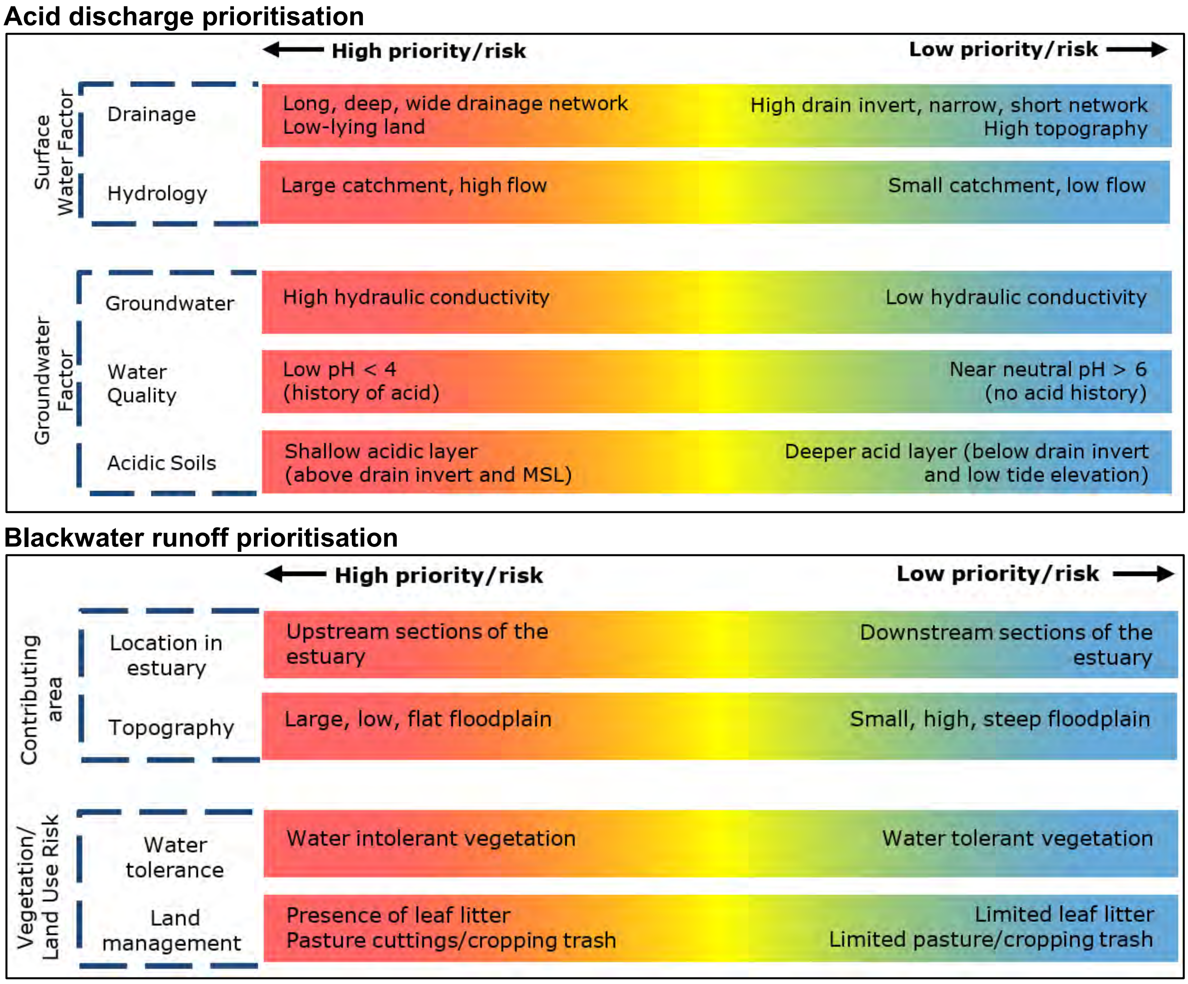

Figure ES-1: Factors influencing from acid sulfate soil discharge and blackwater runoff from NSW coastal floodplain subcatchments

Following the prioritisation of subcatchments, management options have been suggested to guide potential on-ground actions that could be implemented to address the sources of poor water quality from ASS and low oxygen blackwater. Management options have been proposed for the short-term, assuming existing land use practices will remain unchanged, and the long-term, where environmental stressors on subcatchments such as sea level rise may require strategic changes to floodplain management. Management options have been suggested for individual subcatchments taking into consideration:

- Priority ranking for acid and blackwater;
- Proximity to sensitive receivers;
- Condition of existing floodplain infrastructure;
- Historical remediation works;
- Estuarine influence on the floodplain (e.g. tide and salinity levels);
- Current and future land uses;
- Current and future land values;
- The relative costs and benefits of remediating the floodplain; and
- Predicted vulnerability to climate change (sea level rise).

The management options suggested as part of this study are high level and intended to guide the overall strategy that should be considered by floodplain managers when addressing sources of diffuse poor water quality. It is acknowledged that further detailed on-ground investigations are required prior to the commitment to any on-ground actions, including consideration of impacts on local landholders. While this is not specifically addressed as part of this study, a range of factors which influence implementation have been collated to assist floodplain managers during the detailed design of works to improve water quality. Implementation factors to be considered when assessing changes in existing management and in detailed design include:

- Waterway status (natural or artificial);
- Infrastructure and land tenure;
- Land value (including production, purchase and remediation values);
- Future land use planning;
- Location of sensitive receivers; and
- Location of heritage items.

ES.4 Clarence River Floodplain subcatchment prioritisation results

The multi-criteria prioritisation methodology was applied to rank subcatchment drainage areas of the Clarence River floodplain with respect to the risk they pose to the marine estate due to poor water quality associated with ASS discharge and blackwater runoff. The prioritisation methodology utilised a data driven approach to objectively rank the 16 floodplain subcatchments outlined in Figure ES-2. Data considered during this analysis included:

- Topography;
- Groundwater potential flow rate (i.e. hydraulic conductivity);
- Floodplain drainage;
- Subcatchment hydrology;
- Soil parameters including acid concentration;
- Land use; and
- Estuarine and tidal dynamics.

The acid prioritisation assessment considers the volume of acid stored within a floodplain and the potential for it to be transported to the estuary to objectively rank subcatchment areas from the highest to lowest with respect to the risk of acid drainage to the estuary. Within the Clarence River floodplain, the highest five (5) priority subcatchments for acid drainage: Sportsmans Creek (1), Swan Creek (2), Gulmarrad/East Woodford Island (3), Shark Creek (4), and Taloumbi/Palmers Channel (5) were estimated to contribute over 80% of the total acid risk to the estuary. The Sportsmans Creek subcatchment was estimated to individually be the source of 35% of acid risk to the estuary. High risk acid subcatchments were identified in the upper, middle, and lower reaches of the estuary, indicating that acid discharges from the floodplain have the potential to impact all areas of the Clarence River estuary (Table ES-1, Figure ES-3).

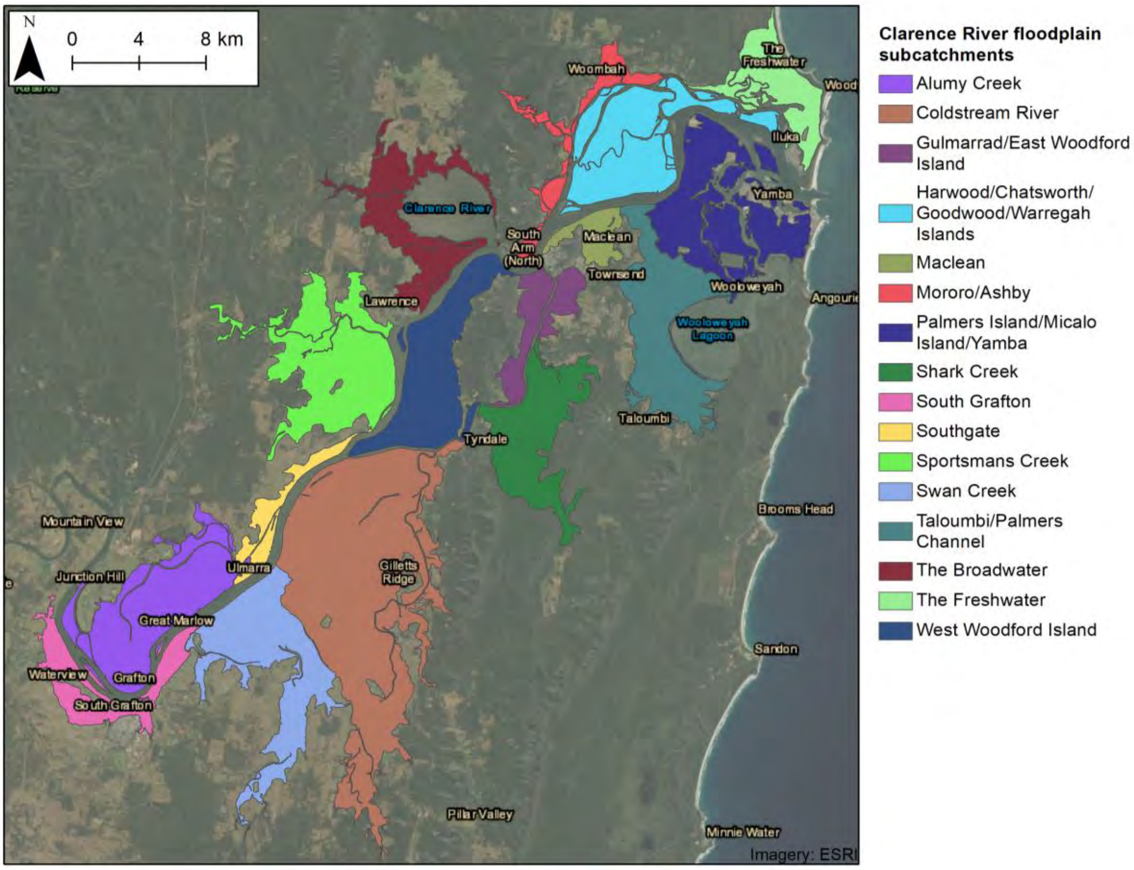

Figure ES-2: Clarence River floodplain subcatchments

Table ES-1: Clarence River floodplain subcatchment priority ranking

Floodplain subcatchment	Acid Rank	Blackwater Rank
Sportsmans Creek	1	2
Swan Creek	2	3
Gulmarrad/East Woodford Island	3	10
Shark Creek	4	5
Taloumbi/Palmers Channel	5	4
Coldstream River	6	1
Mororo/Ashby	7	15
The Broadwater	8	8
Maclean	9	13
Harwood/Chatsworth/Goodwood/Warregah Islands	10	9
Palmers Island/Micalo Island/Yamba	11	14
South Grafton	12	11
West Woodford Island	13	6
Alumy Creek	14	7
Southgate	15	12
The Freshwater	16	16

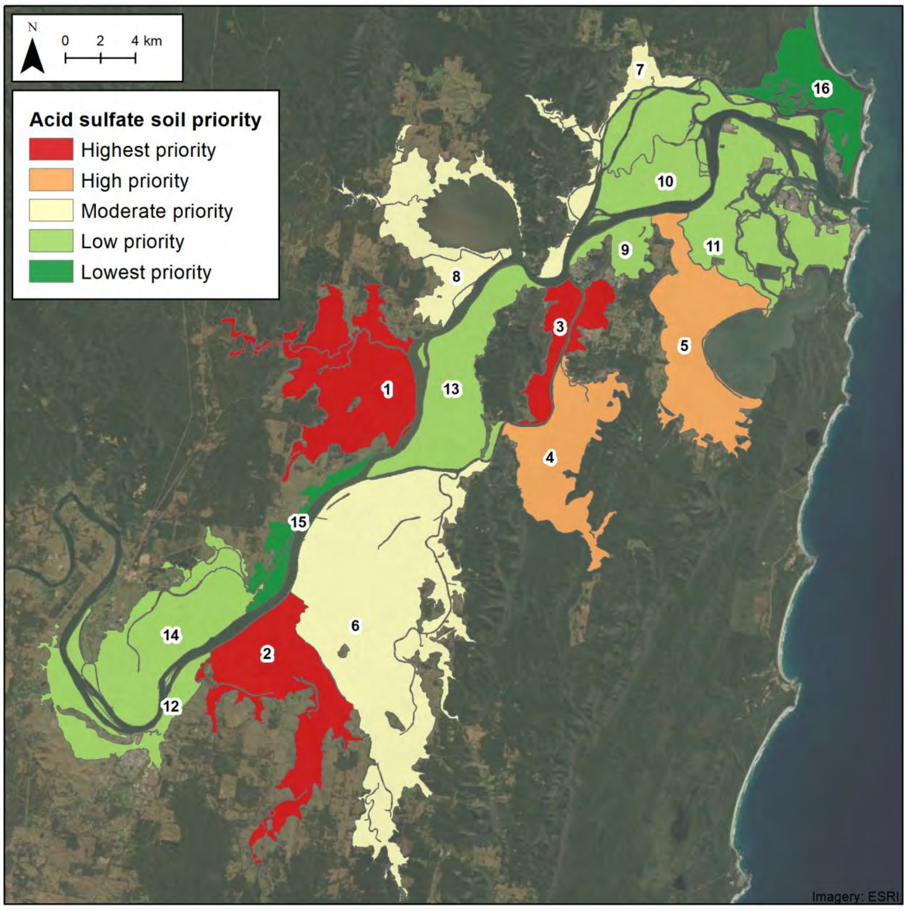

Figure ES-3: Clarence River floodplain subcatchment rankings of the acid prioritisation assessment

Application of the blackwater prioritisation methodology identified areas that are most likely to contribute to blackwater generation due to:

(i) Susceptibility to prolonged floodplain inundation following flood events; and
(ii) Distribution of water tolerant (or intolerant) vegetation.

This data was used to objectively rank subcatchments from highest to lowest based on the risk they pose to the marine estate in terms of discharging low oxygen blackwater to the estuary. This assessment identified that the Coldstream River subcatchment, ranked first in the blackwater prioritisation, accounts for more than 25% of the overall blackwater generation potential in the Clarence River floodplain. The highest three (3) ranked subcatchments (Coldstream River, Sportsmans Creek and Swan Creek), collectively account for over 50% of the total blackwater risk (Table ES-1). While the highest three (3) ranked subcatchments for blackwater generation are located in the mid to upper estuary (Figure ES-4), blackwater generation potential was identified throughout the Clarence River floodplain.

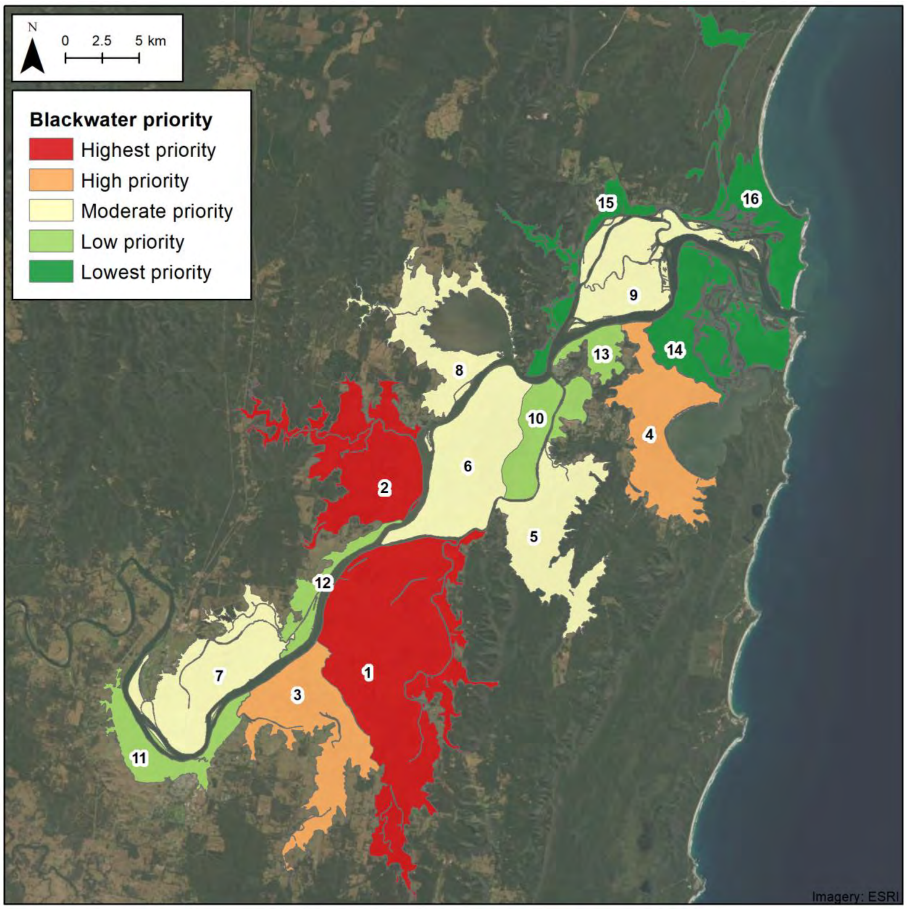

Figure ES-4: Clarence River floodplain subcatchment rankings of the blackwater prioritisation assessment

ES.5 Sea level rise and floodplain drainage vulnerability

Estuaries are situated at the interface of coastal rivers and the ocean and as a result the impacts of climate change will substantially change their physical environment (Heimhuber et al., 2019b). Sea level rise in particular will result in a significant increase in water levels within estuaries, changing the dynamics of estuarine and coastal floodplain environments. When developing management options to improve water quality of the marine estate, it is critical to incorporate the impact of sea level rise on estuarine and floodplain processes.

Assessments of sea level rise typically consider increases in the high tide levels and the subsequent inundation and flooding that may occur as a result. On coastal floodplains, however, drainage infrastructure is designed to function over a tidal cycle, preventing backwater flooding during the high tides and also allowing drainage to occur during low tides. As sea level rise occurs, the low tide level will increase which in turn will reduce the drainage potential of the floodplain and associated drainage networks. An increase in the low tide level will impact:

- Floodgates – as their effective operation is reduced as estuary levels increase; and
- Floodplains – as low-lying areas are unable to be effectively drained and become increasingly wetter.

Detailed hydrodynamic modelling of the Clarence River estuary was completed to assess the vulnerability of floodplain drainage to sea level rise. Historical (~1960s), present day (2020), near future (~2050) and far future (~2100) sea levels were modelled and compared to floodgate infrastructure geometry and floodplain topography to assess floodplain vulnerability to reduced drainage under sea level rise. The assessment identified drainage infrastructure and floodplain areas potentially vulnerable to sea level rise as summarised in Figure ES-5 and Figure ES-6, respectively.

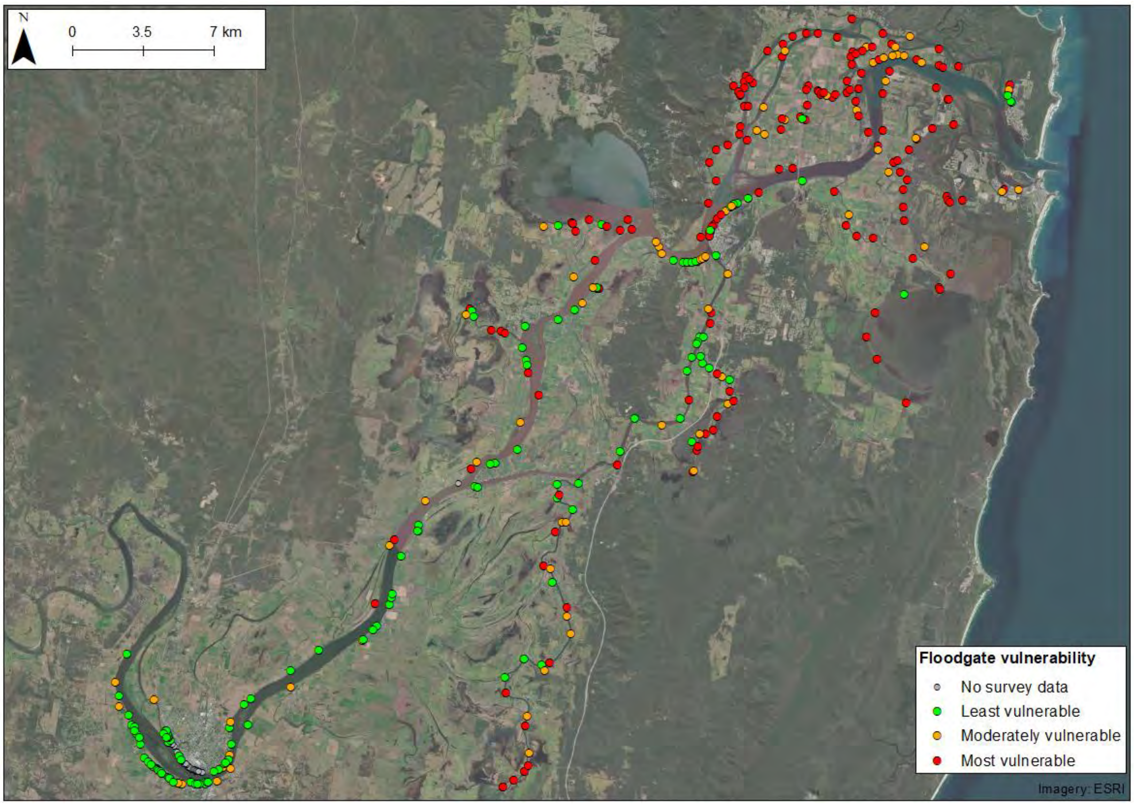

Figure ES-5: Clarence River estuary floodgate vulnerability with sea level rise (far future ~2100)

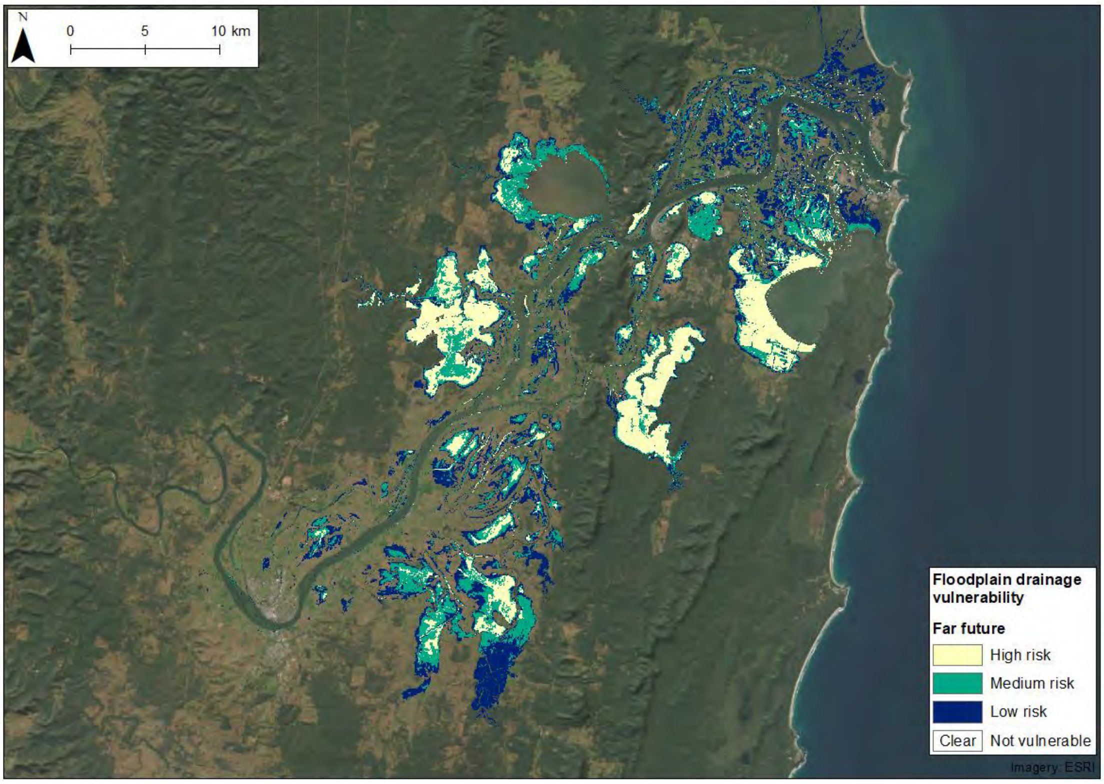

Figure ES-6: Clarence River floodplain vulnerability with sea level rise (far future ~2100)

ES.6 Management options for three priority subcatchments

The top three (3) highest priority subcatchments in the Clarence River floodplain were identified as:

- Sportsmans Creek;
- Swan Creek; and
- Coldstream River.

It is estimated that these three (3) floodplain subcatchments account for approximately 60% of the overall acid generation risk and 53% of the overall blackwater generation risk in the Clarence River floodplain. Addressing water quality issues from these three (3) subcatchments would result in improvements in overall estuary health of the Clarence River floodplain, and significantly benefit the estuarine ecohealth of the immediate downstream waterways which receive regular discharges of poor water quality. A significant amount of work has been done in these subcatchments to address water quality, however further remediation could result in significant improvements to the overall estuarine health of the Clarence River estuary. While paddock-scale remediation is worthwhile, broadscale restoration of natural freshwater or estuarine hydrology and changes in land use in priority areas would result in the greatest improvement in water quality, particularly in the top three (3) priority floodplain subcatchments.

However, any changes in management of these areas will require extensive consultation with local landholders and a comprehensive understanding of, and a plan to mitigate, the social and economic impacts of changes in land management on the community.

The prioritisation methodology is primarily based on subcatchment datasets to determine subcatchment rank within a coastal floodplain, and does not explicitly incorporate the effectiveness of existing remediation works on reducing acid discharge or blackwater generation potential. Existing remediation works are, however, considered in each subcatchment management options.

Sportsmans Creek subcatchment

The Sportsmans Creek subcatchment was ranked first in the ASS prioritisation and was estimated to account for 35% of the acid risk in the Clarence River floodplain. The subcatchment also ranked second in the blackwater prioritisation. A substantial portion of the Sportsmans Creek subcatchment is owned and managed by National Parks and Wildlife Service, however on-going agricultural land uses in some of the lowest sections of the floodplain have limited the ability to implement widespread changes to land management within the National Park. Nevertheless, the existing remediation works, including modification of floodgates and installation of weirs will help to minimise acid drainage from the Sportsman Creek subcatchment. Active management of the existing infrastructure is recommended in the short term to help manage poor water quality discharges.

However, it is acknowledged that to effectively minimise acid and blackwater drainage in the Sportsmans Creek subcatchment, restoration of natural hydrology, including tidal connectivity and floodplain inundation would be required. This may include re-design of artificial levees and flow impediments, including internal floodgates, to restore natural flow paths. Any changes to drainage would have to consider the impacts to local landholders, including those adjacent to the Everlasting Swamp National Park area.

Swan Creek subcatchment

The Swan Creek subcatchment ranked second in the ASS prioritisation and third in the blackwater prioritisation. The main floodgates in the Swan Creek subcatchment have already been modified with lifting devices/sluices that allow controlled tidal flushing and fish passage. In the short-term, the management of these structures should be reviewed to ensure the day-to-day management of the floodgates is optimised to improve water quality without impacting the flood mitigation capacity of the system. As grazing accounts for over 75% of the land use in the subcatchment, the use of weirs and wet pasture management may be able to be encouraged to reduce acid and blackwater discharges.

The suggested long-term management strategy for the Swan Creek subcatchment focuses on the restoration of natural freshwater hydrology, particularly in low-lying backswamp areas. In the long-term, reduced drainage due to sea level rise may result in prolonged inundation of large areas of the Swan Creek subcatchment, and reduced viability of existing land uses. This may provide an opportunity to work with landholders to transition towards the restoration of natural hydrology in this subcatchment.

Coldstream River subcatchment

The Coldstream River is a large tributary of the Clarence River and this subcatchment ranked first in the blackwater prioritisation and sixth in the ASS prioritisation. It potentially accounts for 26% of the overall blackwater generation risk in the Clarence River floodplain. Substantial remediation works have already been completed in this subcatchment to address water quality issues associated with ASS and blackwater, including the modification of numerous floodgates (15 with lifting devices, 7 with auto-tidal floodgates and 1 sluice gate) and the installation of at least four (4) water retention structures.

The existing on-ground works address the majority of the short-term management strategies that can be readily implemented in the Coldstream River subcatchment. The management of existing structures (including dropboard weirs) should be reviewed to ensure that tidal flushing, water retention and wet pasture management strategies are optimised. However, large scale improvements in water quality in this subcatchment will require the restoration of natural freshwater hydrology, particularly in the low-lying backswamp areas. This will likely require prolonged inundation following floods, as well as modification of the existing drainage infrastructure. Such changes are only feasible with substantial input from the community and a plan to mitigate the social and economic impacts on existing landholders.

ES.7 Outcomes and conclusions

Outcomes from the Coastal Floodplain Prioritisation Study for the Clarence River floodplain provide a roadmap for floodplain land managers to directly improve poor water quality associated with diffuse runoff caused by acid and blackwater generation on the coastal floodplain. Specifically, this study has:

1. Ranked subcatchments on the basis of the risk they pose to the marine estate in terms of poor water quality resulting from ASS and blackwater runoff;
2. Suggested potential management options that describe the overall strategy for floodplain management to improve water quality; and
3. Identified and collated key datasets that will be valuable for floodplain management.

It is acknowledged throughout this study that substantial efforts have been made by Clarence Valley Council (especially through the Clarence Floodplain Project since 1997), with the support of local landholders, to address poor water quality from acid sulfate soils and blackwater in the Clarence River estuary. This work has typically included modifying floodgate infrastructure and paddock scale interventions, such as installation of weirs, wet pasture management and drain management. These remediation efforts should be encouraged and commended. However, the scale of on-going large event-based floodplain discharges of blackwater and acid, particularly from the three (3) highest priority subcatchments (Sportsmans Creek, Swan Creek and Coldstream Ricer) can only be substantially addressed through broadscale changes to land use and a restoration of natural floodplain hydrology. Broadscale management changes throughout the floodplain will need to consider, and have a plan to mitigate potential social, cultural, and economic impacts to local landholders. Particularly as sea level rise impacts drainage and agricultural land uses in the lowest lying areas of the floodplain, a catchment wide strategy will be required to assist the community to adapt to a changing environment and to support a future that is environmentally and economically sustainable.

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Glossary of terms

Acid	A substance that has a pH less than 7 (a pH of 7 being neutral i.e. neither acidic nor alkaline). Specifically, an acid has more free hydrogen ions (H^+) than hydroxide ions (OH^-).
Acid export	The mass of acid discharged from a system (e.g. a drain or floodplain). Acid can be exported via two common mechanisms, by either a hydraulic gradient (water level or pressure head difference along a channel or pipeline) or a concentration gradient (natural mixing through a water body from a higher concentration to a lower concentration).
Acid sulfate soil (ASS)	Sediments in which iron sulfides (mainly pyrite) accumulate below the groundwater table in anaerobic conditions. The exposure of these sediments to air enables the oxidation of pyrite/sulfides to produce sulfuric acid. Oxidised acid sulfate soils are referred to as actual acid sulfate soils (AASS), unoxidised acid sulfate soils are referred to as potential acid sulfate soils (PASS).
Alkali	A substance that has a pH greater than 7 (a pH of 7 being neutral i.e. neither acidic nor alkaline). Specifically, an alkali has more free hydroxide ions (OH^-) than hydrogen ions (H^+).
Anaerobic conditions	The absence of atmospheric oxygen (often required for certain biological processes).
Annual exceedance probability (AEP)	The probability of a flood or rainfall event of a predetermined size or larger occurring in a one-year period.
Antecedent conditions	The moisture stored within a catchment prior to a rainfall event.
Australian Height Datum (AHD)	A datum surface for Australia used for measuring elevation. The zero metres AHD height at 30 tide gauges across Australia corresponds to mean sea level as measured from 1966 to 1968.
Auto-tidal gate	A mechanism whereby a small opening on a floodgate flap is allowed to let a controlled volume of water upstream of a floodgate as the water level increases on the downstream side. This can be mechanical or power driven. As the water rises to a designed level (on the downstream side) the mechanism on the gate shuts, closing the small opening on the floodgate flap. This mechanism allows for controlled flushing of waterbodies upstream of a floodgate in addition to fish passage.
Backwater	Water held up in its course (being controlled by downstream conditions) as compared with its normal or natural condition of flow.
Baseflow	Flow of a waterway sustained between periods of rainfall by groundwater discharge.
Bathymetry	The measurement of depth of water from the surface to the bottom a waterbody.
Blackwater	Deoxygenated water usually dark in colour and resulting from decomposing organic matter.
Buoyancy tidal gate	A buoyancy tidal gate (often referred to as a fish gate) is a mechanism whereby a small opening on a floodgate flap is allowed to let a controlled volume of water upstream of a floodgate as the water level increases on the downstream side. As the water rises to a designed level (on the downstream side) the buoyancy mechanism on the gate shuts, closing the small opening on the floodgate flap. This mechanism allows for controlled flushing of waterbodies upstream of a floodgate in addition to fish passage.
Catchment	The land area upstream of a particular point of interest into which precipitation drains. Each waterway has its own individual catchment. Also called a "watershed."
Climate change	A change in climate patterns as a result of increases in atmospheric carbon dioxide.
Connector watercourse	A waterway with either natural or artificial sections that provides a connection between two natural waterbodies.
Crest	The crest is the elevation at which weirs, levees or drop board structures are designed to overtop.
Culvert	Culverts are structures that allow water to move between two open waterbodies and bypass an obstruction such as a levee or road. Culverts have two open ends which do not inhibit flow. However, they can also have separate mechanisms such as floodgates or sluice gates attached to them to further control the flow of water.

Digital elevation model (DEM)	A 3D computer model of land surface elevation. A DEM is composed of a grid of cells which each represent an elevation value. The size of individual grid cells (e.g. 1 m times 1 m or 5 m times 5 m) is one measure of the accuracy of a DEM.
Discharge	Flow rate measured by volume per unit time (usually in cubic metres per second).
Dissolved organic carbon (DOC)	Organically bound carbon present in water that can pass through a membrane filter with a 0.45μm pore size.
Dissolved oxygen (DO)	Atmospheric oxygen that dissolves in water. The solubility of oxygen depends upon temperature and salinity.
Downstream/ upstream	Downstream is the location in a channel that is closest to the ocean. Upstream is the location in a channel that is furthest from the ocean.
Drop board	Drop boards are frames built across a waterway which enable the manipulation of flow and water levels by the insertion of 'boards' into specifically designed slots to act as a barrier to water movement. Drop boards are similar to weirs in that they only allow water to flow over the top of them. Unlike weirs, drop boards are adjustable in height. Multiple boards with different heights can be used to adjust and set the weir level. Drop boards can be fitted to culverts or can be standalone structures.
Drought	A prolonged period of reduced or low precipitation resulting in a shortage of water.
Electrical conductivity (EC)	A measure of dissolved salt in water in the units of micro Siemens per centimetre (μS/cm) usually at a temperature of 25ºC.
Estuary	A semi-enclosed waterbody where fresh water from catchment runoff and saltwater from the ocean mix.
Evaporation	The process of liquid water on the land surface becoming water vapour in the atmosphere.
Evapotranspiration	The sum of evaporation and transpiration.
Exceedance per year (EY)	The likelihood that a flood or rainfall event of a predetermined size will occur a certain number of times within any one-year period.
Flood	High flow of water within a waterway that results in the overtopping of natural or artificial banks (or levees) of a waterbody and inundation of usually dry land.
Floodgate/ floodgate flap	A plate that is hinged on its top edge to cover the outlet of a culvert. The flap is positioned so that it only opens when the water level on the upstream (floodplain side) is higher that the level on the downstream (river side) of the culvert, thereby only allowing water to flow in the downstream direction effectively draining the floodplain. Floodgates often regularly open and close with fluctuating tidal water levels in the river. It is common for floodgates to have rubber seals to prevent leaking. Floodgate flaps can be made of many materials such as aluminium, plastic, fibre glass or wood.
Floodplain	The area of land adjacent to a waterbody that is often relatively flat and usually dry unless exposed to water as occurs during a flood.
Freshwater	Water that contains less than 1,000 milligrams per litre (mg/L) of dissolved solids.
Gate	A term used to describe the part of either a floodgate or sluice gate flow control structure that controls water movement.
Groundwater	Water held under the ground surface within soil and rock formations.
Groundwater table	The upper surface of soil or rock formations that is fully saturated by groundwater.
Headwall	The concrete structure surrounding and supporting a culvert. Floodgate flaps or other mechanisms are usually mounted to the headwall.
Hydraulic gradient	The difference in pressure or elevation of water over a distance. The hydraulic gradient results in the flow of water (from high elevation or pressure to low elevation or pressure).
Hydrodynamics	The branch of science concerned with the movement of, and forces acting on or exerted by fluids.
Hydrodynamic model	A numerical representation of the movement of water through a system.
Hydrograph	A graph showing the level, discharge, velocity, or other property of water with respect to time.
Hydrology	The branch of science concerned with the movement and quality of water in relation to land.
Impermeable layer	A layer of solid material, such as rock or clay, which does not allow water to pass through.
Invert	The elevation of the lowest internal point of a culvert.
Leaching	The process by which soluble materials in the soil such as salts, nutrients, pesticide chemicals or contaminants are dissolved and carried away by water.
Left bank/right bank	The side of a waterway when looking in the downstream direction (i.e. toward the ocean).

LEP	Local Environmental Plan - LEPs are planning instruments that guide planning decisions for local government areas. They do this through zoning and development controls, which provide a framework for the way land can be used. LEPs are the main planning tool to shape the future of communities and also ensure local development is completed appropriately.
LGA	Local Government Area.
Levee	An embankment that prevents or reduces flow from a waterway to the floodplain. Levees can be naturally formed as river banks or manmade for the purpose of flood mitigation or to prevent inundation of low-lying land.
LiDAR	Light detection and ranging technology that can be used to measure ground surface elevations and create DEMs.
Marine estate	Tidal rivers and estuaries, the shoreline, submerged lands, offshore islands, and the waters of the coast up to three nautical miles offshore.
Management area	A subset or smaller area of a subcatchment often delineated based on floodplain tenure and ownership in addition to floodplain hydrological and geomorphological characteristics. Generally, a management area is of small enough scale that implementation of on-ground works to address water quality issues can be completed.
MBO	Mono-sulfidic black ooze – deposits in drainage channels created by iron and sulphur minerals (pyrite) within acid sulfate soils which, when mobilised, can remove oxygen from the water through a chemical reaction.
Obvert	The elevation of the highest internal point of a culvert.
Organic matter	Substances made by living organisms and based on carbon compounds.
Peak flow	The maximum instantaneous discharge of a waterway at a given location.
pH	A measure of the acidity or alkalinity of water. Water with a pH of 7 is neutral; lower pH levels indicate increasing acidity, while pH levels higher than 7 indicate increasing alkalinity
Pipe	A pipe is a circular culvert. Pipes can be made of many materials such as concrete, PVC or fibre glass.
Precipitation	Water that falls on land surfaces and open waterbodies as rain, sleet, snow, hail or drizzle.
River	A major watercourse carrying water to another river, a lake or the ocean.
Runoff	Excess rainfall that becomes streamflow.
Salinity	The total mass of dissolved salts per unit mass of water. Seawater has a salinity of about 35g/kg or 35 parts per thousand (ppt).
Sediment	Material suspended in water or deposited from suspension.
Seepage	The infiltration of water from surface waterbodies to the groundwater.
Sluice/sluice gate	A gate that operates by sliding vertically to control water flowing through or past a restriction point. Sluice gates act so that water flows underneath the 'sluice' or the sliding section of the gate. A sluice gate can be set to different levels to control the volume of water that flows. There are many different designs for sluice gates.
Soil profile	A vertical section of soil (from the ground surface downwards) where features such as layers (soil horizons), texture, structure, consistency, colour and other characteristics of the soil can be observed.
Streamflow	The flow of water in open waterbodies (such as streams, rivers or channels).
Subcatchment	A section of the floodplain that is geologically and hydrologically similar but can also be delineated based on floodplain management objectives.
Surface water	Water that flows or is stored on the Earth's surface.
Tidal exchange	The proportion of water that is flushed away and replenished with new ocean water each tidal cycle.
Tidal limit	The maximum distance upstream of a waterway where the influence of tidal variation in water levels is observed.
Tidal planes	Reference elevations that define regular tide elevations, including: MHWS - Mean High Water Springs MHW - Mean High Water MSL - Mean Sea Level MLW - Mean Low Water MLWS - Mean Low Water Springs
Tidal prism	The volume of water that flows in and out of an estuary during a tidal cycle (e.g. high tide to low tide).
Transpiration	The release of water vapour from plants to the atmosphere.
Tributary	A smaller river or stream that flows into a larger waterbody.

Watertable	The surface of water whether it is under or above ground.
Waterbody	Either: An artificial body of water, including any constructed waterway, canal, inlet, bay, channel, dam, pond, lake or artificial wetland, but does not include a dry detention basin or other stormwater management construction that is only intended to hold water intermittently; or A natural body of water, whether perennial or intermittent, fresh, brackish or saline, the course of which may have been artificially modified or diverted onto a new course, and includes a river, creek, stream, lake, lagoon, natural wetland, estuary, bay, inlet or tidal waters (including the sea).
Watercourse	Any river, creek, stream or chain of ponds, whether artificially modified or not, in which water usually flows, either continuously or intermittently, in a defined bed or channel, but does not include a waterbody (artificial).
Waterway	The whole or any part of a watercourse, wetland, waterbody (artificial) or waterbody (natural).
Weir	Weirs are permanent structures that block a channel and only allow water to flow over the top of them.
Winch	A mechanism used to open floodgate flaps or sluice gates. The winch system usually involves pulling the gates open via chains or cables.

1 Introduction

1.1 Preamble

The Marine Estate Management Strategy (MEMS) (Marine Estate Management Authority, 2018) is a NSW state wide strategy to protect and manage waterways, coastlines and estuaries over a ten year period 2018 – 2028. Initiative 1 of the Strategy is focused on improving water quality. Major sources of poor water quality across the marine estate include acid sulfate soil (ASS) and blackwater runoff into our estuaries. Over the past 25+ years, significant efforts have been made by local councils and landholders to remediate ASS and blackwater drainage, however this has been limited by insufficient funding, resources, and community willingness. To fill knowledge gaps and enable targeted remediation efforts and land management decisions, Department of Primary Industries (DPI) – Fisheries commissioned the Coastal Floodplain Prioritisation Study, based on a method detailed in Glamore and Rayner (2014) and adapted to integrate the MEMS approach for achieving environmental outcomes that consider social, cultural and economic benefits, to prioritise floodplain subcatchments in seven (7) coastal floodplains in NSW.

This report provides an evidence based assessment of floodplain subcatchment drainage areas that contribute poor water quality to the Clarence River estuary. Poor water quality from diffuse agricultural runoff has been identified as the highest priority threat to the environmental assets within estuaries in NSW, as outlined in the threat and risk assessment (TARA) (Fletcher and Fisk, 2017). Diffuse agricultural runoff was also identified as a significant threat to the social, cultural and economic benefits derived from the marine estate. In particular, the TARA highlights the threat posed to estuaries from acid discharges and low oxygen blackwater runoff associated with modified floodplain uses and drainage. To address this, subcatchments in the Clarence River estuary have been prioritised based on the risk of generating poor water quality from ASS and blackwater drainage. Following the priority risk assessment, management options for short and long-term planning horizons have been suggested, outlining potential high level land management options for each subcatchment to address acid and blackwater drainage issues. This study identifies localised management responses that target sources of poor water quality throughout the floodplain. The management options in this study are intended to provide a guide to further improve water quality, although it is acknowledged that further work will be required to assess the applicability of on-ground works at a given location. Any changes in management of these areas will require consultation with local landholders and a comprehensive understanding of, and a plan to mitigate, the social and economic impacts of changes in land management on the community. The outcomes from the study will provide an overview of floodplain processes and datasets, provide potential management responses to poor water quality sources, and facilitate the streamlined implementation of management options into the future.

This study was funded by the NSW Government under the Marine Estate Management Strategy (MEMS). The ten-year Strategy was developed by the NSW Marine Estate Management Authority (MEMA) to coordinate the management of the marine estate. The study was commissioned by NSW Department of Primary Industries - Fisheries under the MEMS Stage 1 and delivered by staff at the Water Research Laboratory (WRL) of the School of Civil and Environmental Engineering at UNSW Sydney.

1.2 Connection to other reports

The prioritisation of the Clarence River floodplain subcatchments and associated management options presented in this report is an application of the methods outlined in the Coastal Floodplain Prioritisation Study – Background and Methodology (Rayner et al., 2023) (i.e. the 'Methods report'). The Methods report outlines the theoretical processes behind the applied prioritisation approach and provides comprehensive detail and justification on the study approach and methods used in this report.

The Coastal Floodplain Prioritisation Study covers seven (7) NSW coastal floodplains:

- Clarence River floodplain (this report);
- Tweed River floodplain (WRL TR2020/04);
- Richmond River floodplain (WRL TR2020/05);
- Macleay River floodplain (WRL TR2020/07);
- Hastings River floodplain (WRL TR2020/08);
- Manning River floodplain (WRL TR2020/09); and
- Shoalhaven River floodplain (WRL TR2020/10).

The subcatchment prioritisations for each of these floodplains are documented in individual reports. Note that prioritisation results between individual floodplains are not directly comparable.

1.3 Coastal Floodplain Prioritisation Method

The Coastal Floodplain Prioritisation Method (Rayner et al., 2023) provides an objective approach to assess subcatchments within a coastal floodplain and identify areas that pose the greatest risk of poor water quality from acid sulfate soil discharges and low dissolved oxygen blackwater runoff. The method does not address additional water quality issues, such as nutrient export or catchment runoff, which may also pose a significant risk to the estuarine health of the marine estate. Instead, it focuses specifically on the generation of acid discharge and blackwater within each estuary. The present report focuses on the Clarence River estuary and adjoining floodplain subcatchments.

The study approach features two (2) primary prioritisation methods that independently assess and rank floodplain subcatchments based on the risk of:

1. Discharge from acid sulfate soils; and
2. Generation of low oxygen 'blackwater' runoff.

The prioritisation method utilises a multi-criteria analysis to assess the risk of poor water quality from floodplain subcatchments and ranks the subcatchments relative to their contribution to these key water quality issues. Figure 1-1 provides an overview of the study approach.

This report provides a prioritised list of floodplain subcatchments from where the greatest risk of acid and blackwater within each floodplain originate. The greatest potential benefit to the estuary can be gained by reducing the sources of poor water quality from the subcatchments according to the priority order. The individual floodplain assessments and prioritisations provide subcatchment management options and data summaries to guide land managers and decision makers in implementing on-ground actions on both floodplain and paddock scales.

In addition to the prioritisation and management options, collated in this report and the Methods report (Rayner et al., 2023), there are a number of implementation constraints. These are factors that do not necessarily influence physical processes and the development of the management plans but will influence their implementation. Implementation constraints that have been collated include:

- Waterway status (natural or artificial);
- Infrastructure and land tenure;
- Land value (including production, purchase and remediation values);
- Future land use planning;
- Location of sensitive receivers; and
- Location of heritage items.

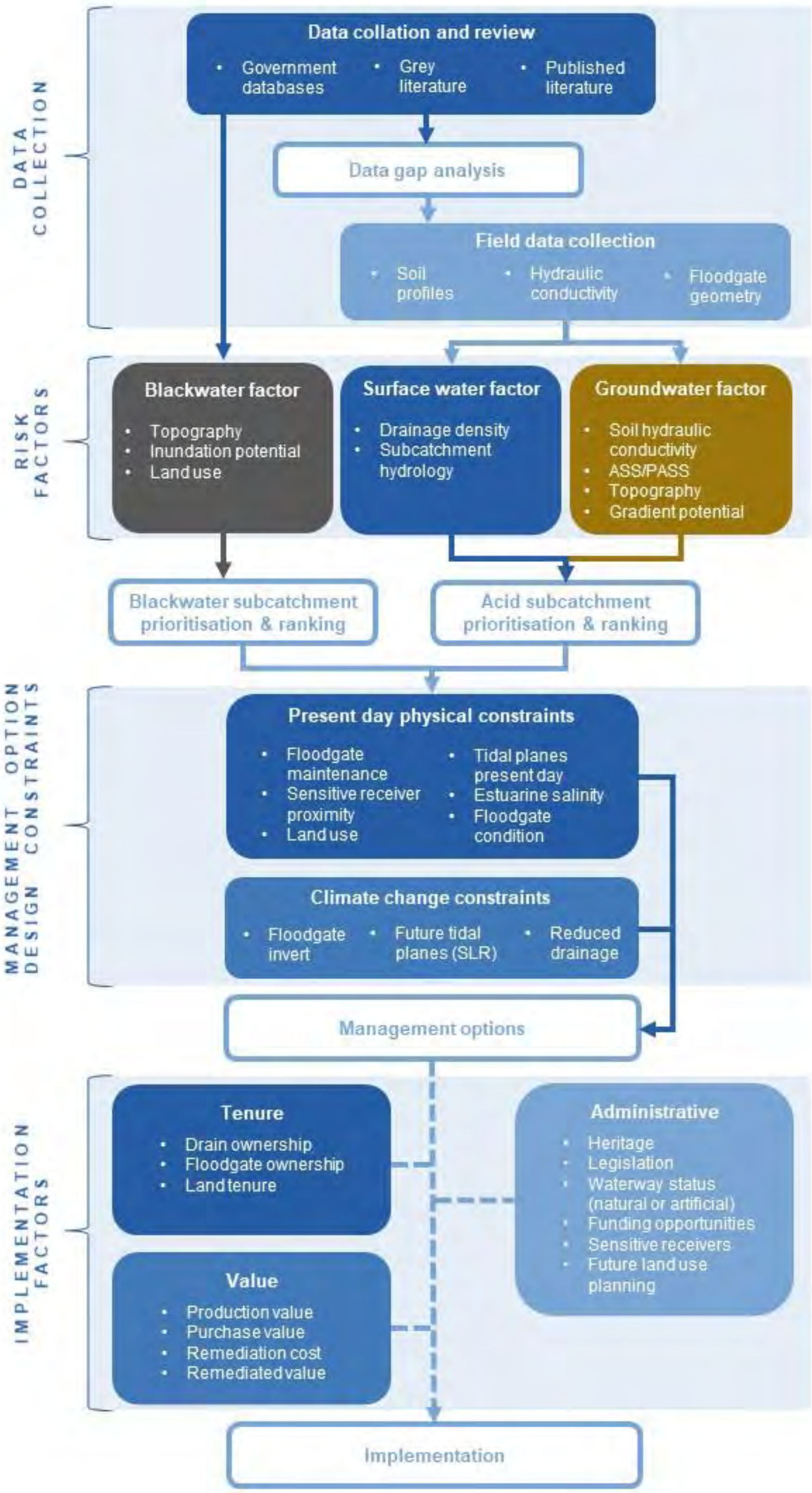

Figure 1-1: Study approach overview

1.4 Clarence River floodplain prioritisation

The Clarence River estuary floodplain is located on the north coast of NSW between the towns of Yamba and Iluka in the east and the town of Grafton to the west. European settlement of the area began in the mid-19th century (Tulau, 2011). Extensive artificial floodplain drainage was constructed in the late 19th century and throughout the 20th century for flood protection purposes and to facilitate agricultural development (Tulau, 1999a). Floodplain development and drainage has had unintended impacts on estuarine water quality with the oxidation of acid sulfate soils, and the establishment of non-water tolerant vegetation in historically low-lying wetland areas (Johnston et al., 2003a; Johnston et al., 2003b). Although acid sulfate soils are naturally occurring sediments, and blackwater discharge historically occurred in undeveloped, natural floodplains, the construction of man-made drainage channels exacerbated these issues and has contributed to poor water quality throughout the greater Clarence River estuary.

This report summarises the application of the acid sulfate soil and blackwater subcatchment prioritisation methodologies on the Clarence River estuary floodplain (defined as the area below 5 m AHD). On-ground management options have been suggested for each subcatchment, based on the results of the dual prioritisation. Some management strategies can be implemented in the short term with minimal impacts to existing land uses, while others require substantial changes to land management to create effective improvements in water quality outcomes. The management options provided in this study are intended to be a guide only, and no on-ground work is recommended without further studies into the applicability and potential impacts of any changes in management. The following factors were considered to develop on-ground management options for each subcatchment area:

- Priority ranking for acid and blackwater;
- Proximity to sensitive receivers;
- Condition of existing floodplain infrastructure;
- Historical remediation works;
- Estuarine influence on the floodplain (e.g. tide and salinity levels);
- Current and future land uses;
- Current and future land values;
- The relative costs and benefits of remediating the floodplain; and
- Predicted vulnerability to climate change (sea level rise).

The outcomes of this study aim to provide the basis for a strategic approach to address ASS and blackwater discharges in the Clarence River floodplain, as well as collecting and collating key datasets that will inform on-going and future decision making and design of floodplain drainage and flood mitigation infrastructure. Implementing the recommended options will ensure that subcatchments with the greatest potential impacts are prioritised for strategic land use decisions and remediation of water quality risks. As such, this will ensure that future investments in subcatchment management actions are evidence based, providing the best value for money and environmental outcomes.

1.5 About this report

This report comprises the following sections:

- **Chapter 2** presents the drainage subcatchments considered in the Clarence River floodplain;
- **Chapter 3** provides background information describing the floodplain drainage and presence of ASS and blackwater in the Clarence River floodplain;
- **Chapter 4** provides an overview of the ASS and blackwater prioritisation;
- **Chapter 5** presents the outcomes of the ASS prioritisation in the Clarence River floodplain;
- **Chapter 6** presents the outcomes of the blackwater prioritisation in the Clarence River floodplain;
- **Chapter 7** provides information on the impact of climate change on floodplain drainage;
- **Chapter 8** outlines the management options developed for each of the subcatchments; and
- **Chapter 9** provides a summary and recommendations.

The following appendices have also been included to provide additional information and summaries of data used and collected for the study:

- **Appendix A** Floodplain drainage;
- **Appendix B** Catchment hydrology;
- **Appendix C** Groundwater saturated hydraulic conductivity data;
- **Appendix D** Acid sulfate soil distribution;
- **Appendix E** Blackwater elevation thresholds;
- **Appendix F** Floodplain infrastructure;
- **Appendix G** Cross sections;
- **Appendix H** Water quality;
- **Appendix I** Hydrodynamic modelling;
- **Appendix J** Sensitive environmental receivers;
- **Appendix K** Heritage; and
- **Appendix L** Soil profile data sheets.

2 Subcatchment delineation

2.1 Preamble

The prioritisation of ASS and blackwater generation potential in this study compares and ranks drainage units or subcatchments on the Clarence River floodplain for areas below 5 m AHD. The delineation of subcatchments can influence the results of the prioritisation and requires careful consideration given the highly connected nature of low-lying coastal floodplain areas. The process of delineating the subcatchments primarily includes consideration of:

- Topography data (from aerial LiDAR surveys);
- Waterway alignment data; and
- Management boundaries (e.g. as specified in CZMP or CMP documentation).

The primary data used for subcatchment delineation was topographical and waterway data which allows for the determination of hydrological flow paths. Using this data allows each subcatchment to be delineated as a single hydrological unit (as far as reasonably practical). This was deemed the most important factor in the subcatchment delineation process as it then allows each subcatchment to be managed as a discrete unit. This section outlines the subcatchments developed for the Clarence River floodplain, which are used throughout this study.

2.2 Subcatchments of the Clarence River floodplain

Subcatchments were delineated throughout the Clarence River floodplain in the Clarence Estuary Management Plan (EMP) (Umwelt, 2003). However, the subcatchment boundaries in the EMP focussed on reaches of the main waterways, rather than the floodplain itself. As the focus of this study is on the floodplain, the subcatchment boundaries were redefined to more appropriately represent different floodplain drainage areas that contribute to acid and blackwater generation. The Coastal Zone Management Plan (CZMP) for Wooloweyah Lagoon (White, 2009a) was used to assist in determining boundaries of the Talumbi/Palmers Channel and Palmers Island/Micalo Island/Yamba subcatchments to align the management actions in these areas.

The subcatchments in the Clarence River floodplain are shown in Figure 2-1.

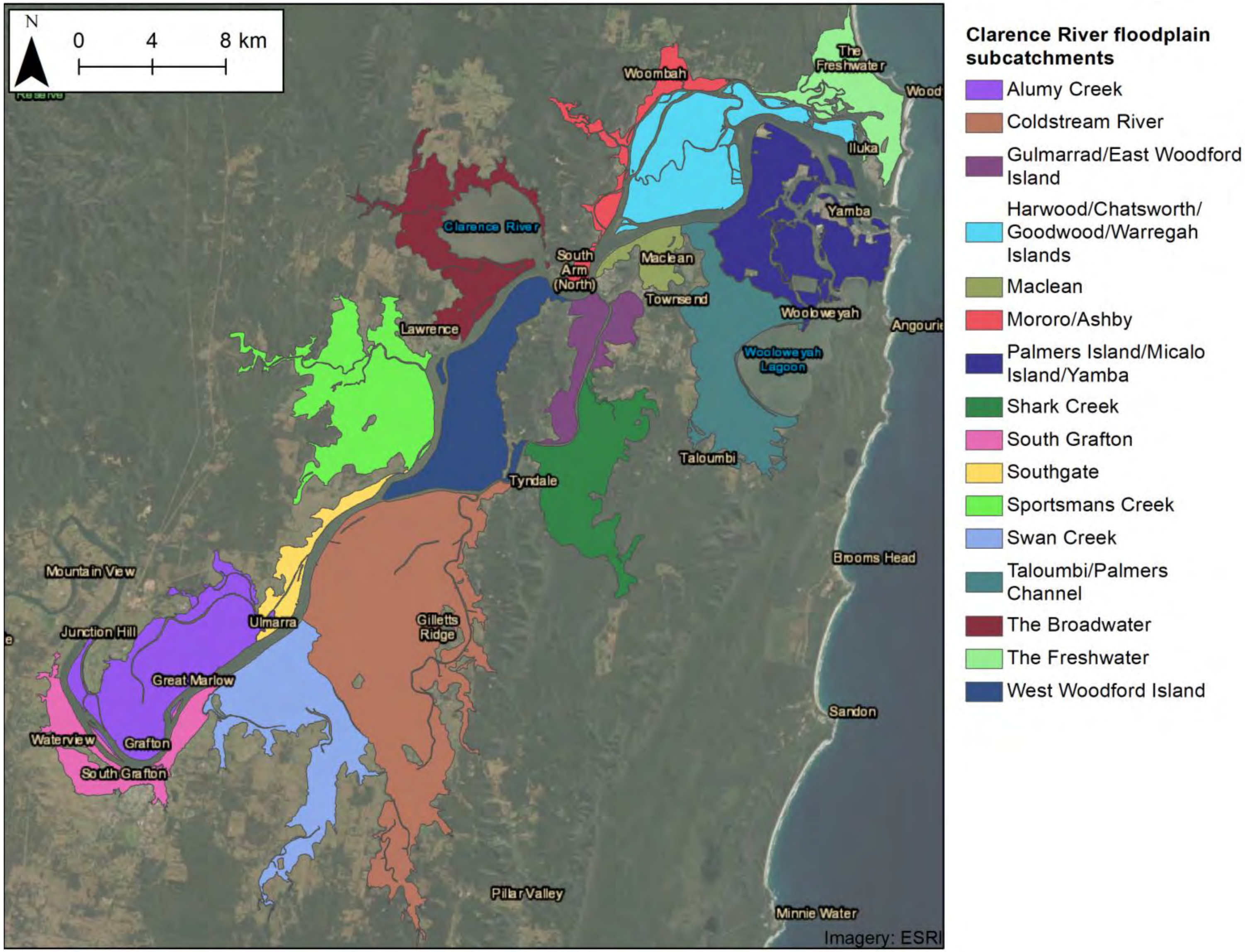

Figure 2-1: Subcatchments in the Clarence River floodplain

3 Background

3.1 Preamble

This section provides background information on the Clarence River floodplain, describing the history of the floodplain drainage, ASS distribution, blackwater runoff events, and floodplain land use and tenure. General background on ASS oxidation and blackwater formation can be found in Sections 3 and 5 of the Methods report (Rayner et al., 2023), respectively.

3.2 Local government areas and county councils

Local and county government bodies play a key role in maintaining floodplain drainage assets and management of estuarine water quality. The Clarence River floodplain is within the boundaries of the Clarence Valley Council (CVC), who manage flood mitigation and drainage assets (Figure 3-1:). This council area was formed in 2004 through the amalgamation of parts of five (5) smaller local government areas. Prior to 2004, flood mitigation throughout the floodplain was managed by Clarence River County Council (CRCC).

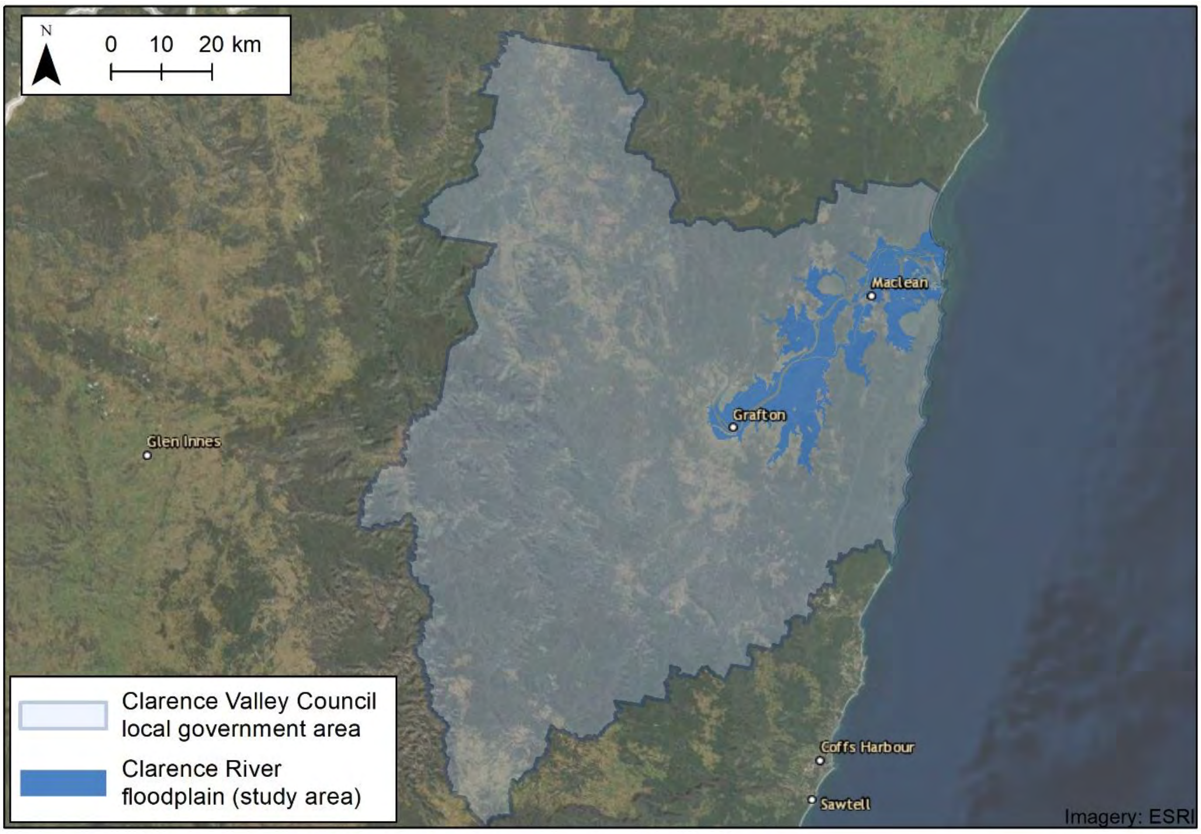

Figure 3-1: Clarence Valley Council local government area

Under the Environmental Planning and Assessment Act (1979) a Local Environmental Plan (LEP) is required for each LGA. LEPs guide the strategic planning decisions for local councils within their LGAs. This is achieved through zoning and development controls which outline the way in which land can be used, including land on coastal floodplains.

3.3 Floodplain history

The Clarence River floodplain (up to 5 m AHD) covers an area of approximately 810 km^2, with a total catchment size with 22,400 km^2 (Manly Hydraulics Laboratory, 2000). The Clarence River estuary generally flows north east and is joined by many tributaries before discharging between Iluka and Yamba as shown in Figure 3-2. Downstream of Maclean, the floodplain includes a number of low elevation islands, including Harwood, Chatsworth, Goodwood, Palmers and Micalo Islands (Tulau, 1999a). Further upstream, large areas of low elevation backswamp occur at The Broadwater, Everlasting Swamp, Shark Creek, Coldstream River and Swan Creek (see Figure 3-3).

The Clarence River floodplain has undergone extensive drainage and hydrological modification since it was settled in the 1800s, including the installation of agricultural drains, levees and tidal floodgates. The earliest drainage works date back to the late 1800s (Tulau, 1999a), the most notable flood mitigation works were completed in the 1960 - 1970s by Clarence River County Council (CRCC). These early works were primarily undertaken for flood mitigation, to promote dry land agricultural production, and prevent saline intrusion onto the backswamp areas of the floodplain (Tulau, 2011). Tulau (2011) notes that despite the often misleading use of terminology, the 1950-70s 'flood mitigation' schemes were overwhelmingly swamp drainage schemes.

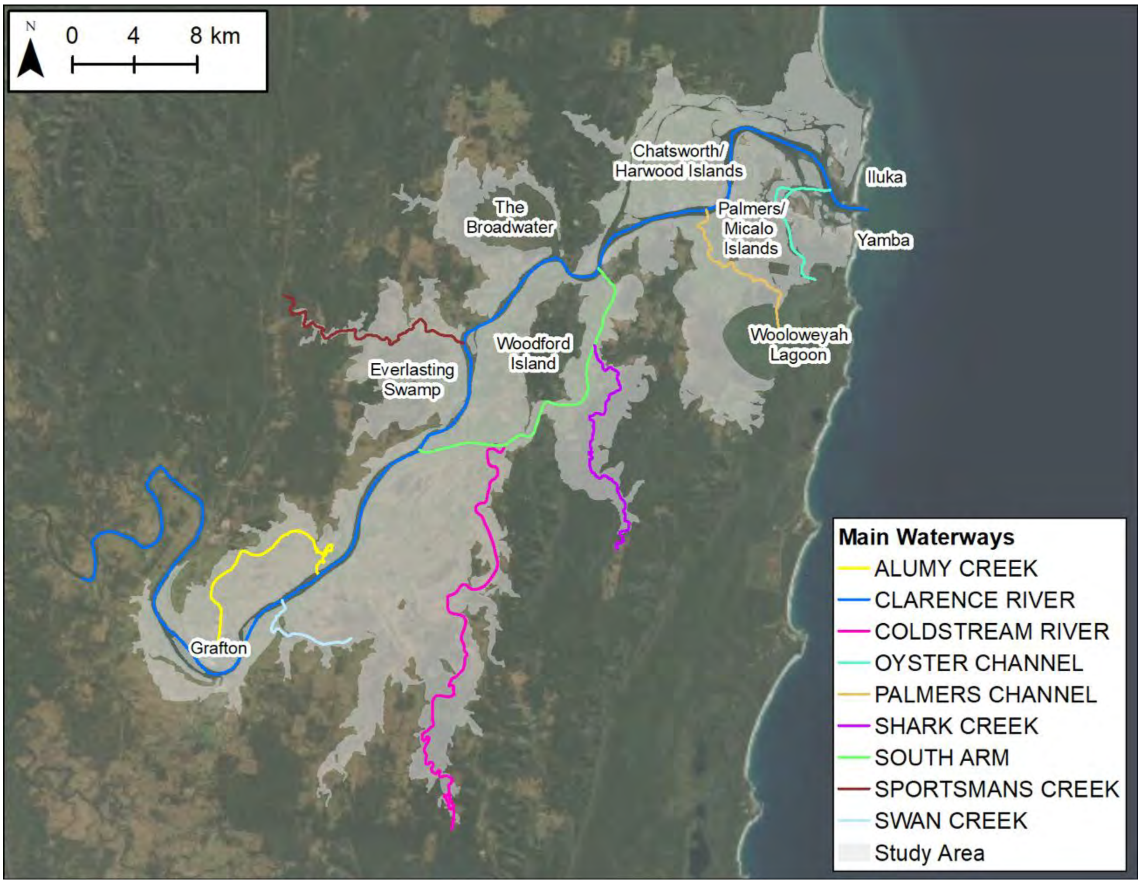

Figure 3-2: Key locations and waterways in the Clarence River floodplain

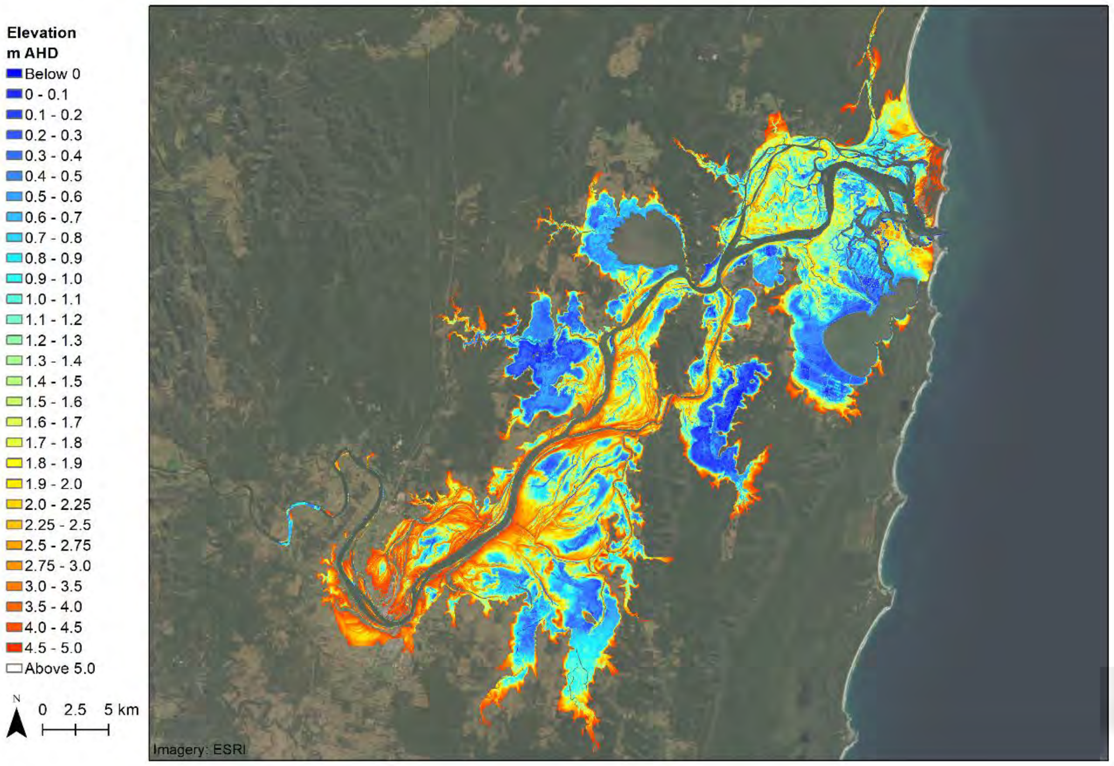

Figure 3-3: Digital elevation map of the Clarence River floodplain

A timeline of key events and drainage works on the Clarence River floodplain (Tulau, 2011) includes:

- Early 1840s – Settlement of the Clarence River floodplain began;
- 1849 – The establishment of the town of Grafton;
- 1859 – Colonial Sugar Refining (CSR) Company opened its first mill on the Clarence River at Southgate and sugar cane cultivation began;
- 1860s – Agricultural expansion intensifies throughout NSW northern rivers, as a consequence of government incentives for the purchase of land;
- 1902 to 1920 – First organised attempts to coordinate drainage of North Coast floodplain backswamps. In the Clarence River floodplain, Alipou Creek, James Creek and others were included in the list of swamps drained under the Water and Drainage Act 1902;
- 1930s – Floodplain drainage works started at Everlasting Swamp (Creighton, 2013);
- 1960 to 1970s – Extensive drainage of wetlands in NSW's northern rivers occurred via state funded flood mitigation works. This included deepening and straightening of existing drainage systems and the installation of drainage control structures such as one-way floodgates. Clarence River County Council (CRCC) assumed responsibility of all flood mitigation activities to provide catchment wide flood mitigation planning. Areas targeted for major drainage works constructed during 1960 and 1970s included:

  - Broadwater peninsula (1965);
  - Woodford Island (1965-66);
  - Harwood Island (1965-67);
  - Swan Creek (1965, 1969);
  - Chatsworth Island (1966);
  - Ashby Island (1966);
  - Warregah Island (1966);

    - James Creek (1966);
    - Southgate (1966);
    - Sportsmans Creek (1966);
    - Shark Creek (1966-67);
    - Palmers Island (1966, 1969); and
    - Wombah (1967).

- Late 1970s – By this stage, all the major coastal floodplains and the vast majority of backswamps have large, deep drains with major floodgates. In the Clarence, flood mitigation and drainage works focussed on more urban areas, including works undertaken in the following locations:

    - North Grafton (1969, 1970, 1978);
    - South Grafton (1969, 1972, 1973, 1979);
    - Ulmarra (including West Ulmarra drain) (1973, 1976);
    - Maclean (1976); and
    - Goodwood Island (1974).

- 1980s to 1990s – Drainage works in the central part of Everlasting Swamp completed in early 1980s, with further works undertaken in 1998 to increase drainage north into Teal Lagoon (Glamore et al., 2019; Tulau, 1999a).
- 1997 – Creation of the Clarence Floodplain Project (CFP) by major Clarence floodplain stakeholders to address the environmental impact of flood mitigation structures. Over the following two (2) decades, a substantial number of remediation projects were completed in this program with funding primarily from State and Federal governmental grants (Clarence Valley Council, 2010) and these are discussed further in Section 3.7.2.

A schematic of floodplain evolution indicating the influence of extensive drainage works and its conceptual progression from past to present hydrological conditions is presented in Figure 3-4.

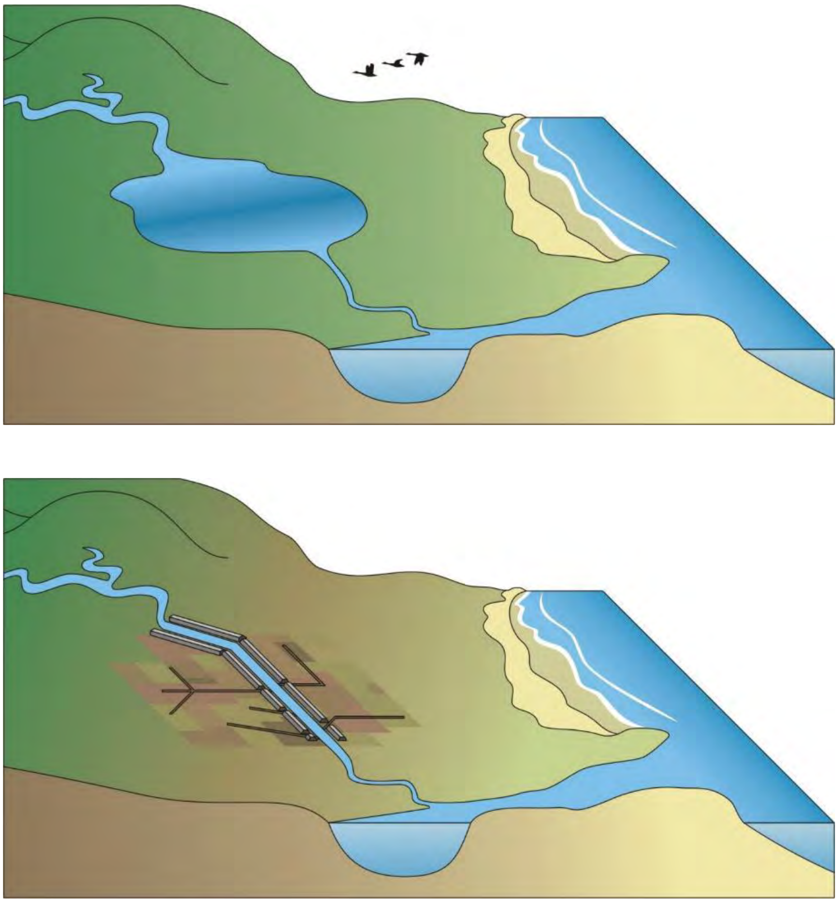

Figure 3-4: Schematic of floodplain evolution following European settlement

3.4 Land use and tenure

Although land use in the Clarence River valley is varied, sugar cane is common in the lower to mid estuary floodplain, particularly around Woodford Island, Chatsworth Island, Harwood Island and Palmers Island. Upstream of Woodford Island, grazing is the predominate land use. Land uses in the Clarence River floodplain for areas below 5 m AHD are shown in Figure 3-5 (refer to Section 9 of Methods report for more detail).

There are a number of areas that are owned and managed by National Parks and Wildlife Service (NPWS) in the Clarence River floodplain, including:

- Clarence Estuary Nature Reserve on Micalo Channel near Yamba;
- Bundjalung National Park, near Iluka; and
- Everlasting National Park, near Lawrence.

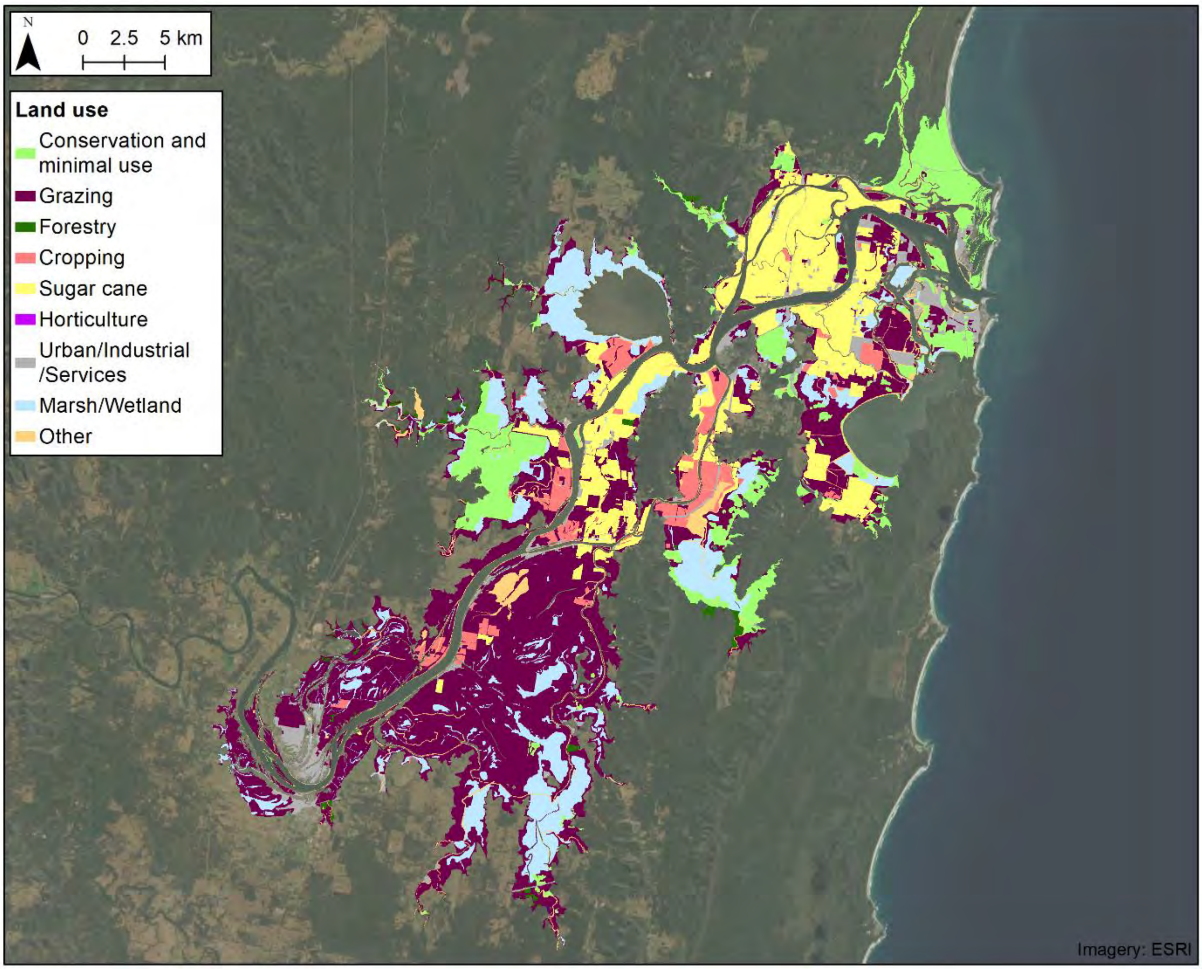

Figure 3-5: Land use in Clarence River floodplain, 2017 (DPIE, 2013; DPIE, 2020)

3.5 Acid sulfate soils in the Clarence River Estuary

This section provides a brief overview of the formation and export of acid from acid sulfate soils (ASS) in coastal floodplains and the presence of ASS on the Clarence River floodplain. Detailed information on the formation, export and impacts of ASS is provided in Section 3 of the Methods report (Rayner et al., 2023).

Acid sulfate soils (ASS) are common on coastal floodplains in NSW (Naylor et al., 1998) and were naturally deposited in low energy environments (e.g. backswamps) during the last 10,000 years. These sediments are benign when permanently inundated in natural swamp lands. However, when floodplain backswamps are drained and the sediments are exposed to oxygen, they can discharge sulfuric acid and toxic metal by-products into the receiving estuarine waters. In areas affected by ASS, the combination of deep drainage channels and one-way floodgates increase ASS oxidation, create acid reservoirs, and restrict potential buffering (or neutralisation) of acid by tidal waters (Johnston et al., 2003a; Stone et al., 1998).

Acidic discharge causes adverse environmental, ecological and economic impacts to the floodplain itself as well as the downstream estuary (Aaso, 2000). Impacts to aquatic ecology can be severe, including acid discharge events leading to fish (Winberg and Heath, 2010) and oyster mortality (Dove, 2003b).

3.5.1 ASS distribution in the Clarence Region

The acid pollution hazard in NSW was originally mapped on the Acid Sulfate Soil Risk Maps prepared by Naylor et al. (1995). The study revealed that the Clarence River floodplain contained an area of over 630 km^2 of high-risk ASS soil below an elevation of approximately 5 m AHD, although the majority of high risk ASS is located below 1 m AHD, as shown in Figure 3-6.

The extent and severity of ASS on the Clarence River floodplain has been confirmed by numerous investigations. The following areas have been identified by various studies as acid hotspots:

- Everlasting Swamp (within the Sportsmans Creek subcatchment) (Tulau, 1999a; Umwelt, 2003);
- Shark Creek (Tulau, 1999a; Umwelt, 2003);
- Alumy Creek (Tulau, 1999a; Umwelt, 2003);
- Lower estuary islands (within the Taloumbi/Palmers Channel and Palmers Island/Micalo Island/Yamba subcatchments) (Tulau, 1999a; Umwelt, 2003); and
- Coldstream River (Umwelt, 2003).

Available data was analysed to describe the distribution of ASS across the Clarence River floodplain. This information was obtained from the NSW Department of Planning Industry & Environment (DPIE) eSPADE Database and recent field investigations completed by WRL, as described in Appendix D. eSPADE provides access to soil profile data and information, including spatial data, reports and imagery, primarily sourced from the NSW Soil and Land Information System (SALIS). This information is useful in understanding the existing distribution and potential risk of stored acidity within floodplain sediments.

The minimum pH at each available location is shown in Figure 3-7. Low pH (<5) has been observed in the Clarence River floodplain, particularly near Sportsmans Creek, the Coldstream River, Swan River, Shark Creek and The Broadwater.

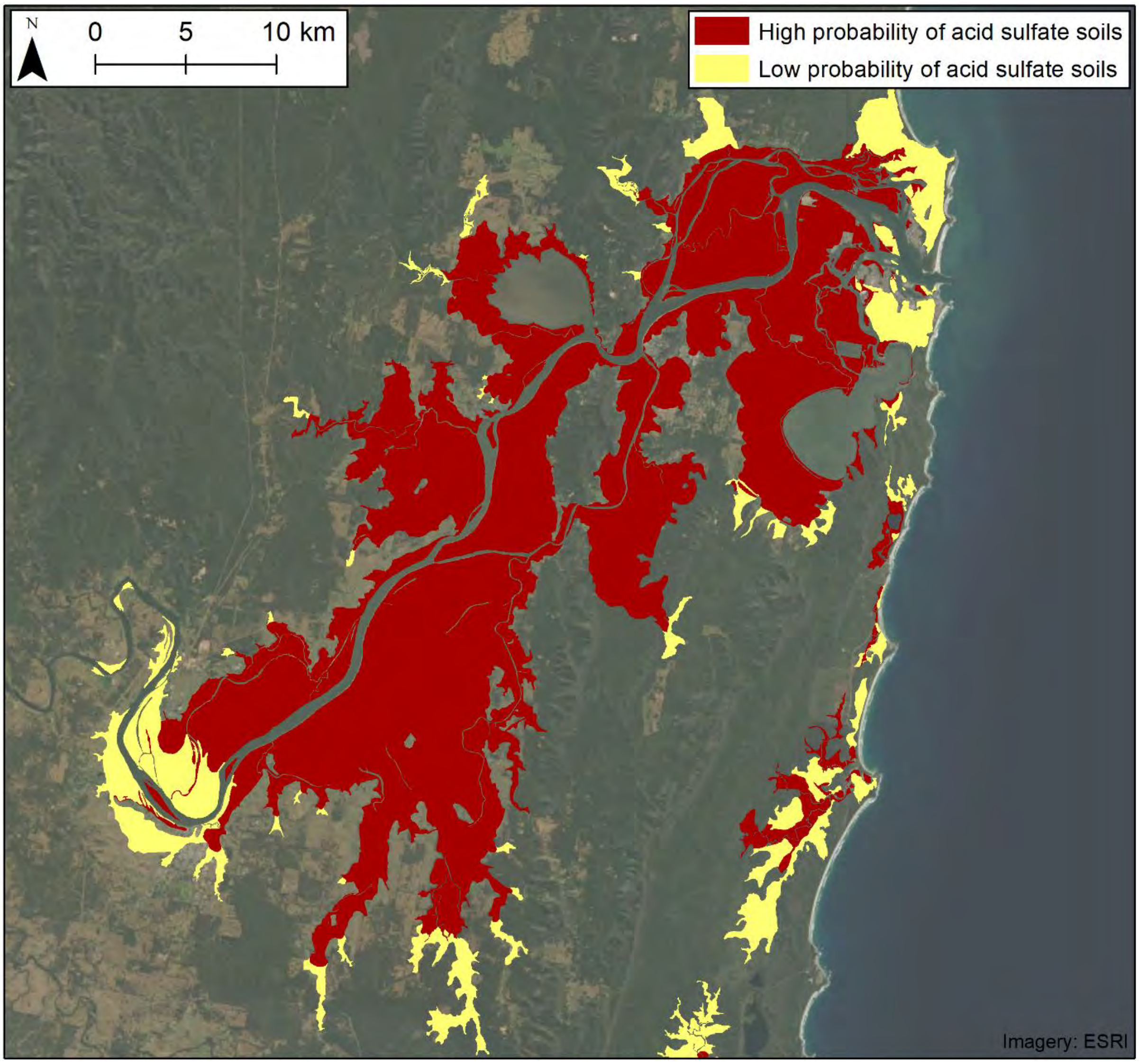

Figure 3-6: NSW Government ASS risk map of the Clarence River floodplain (Naylor et al., 1995)

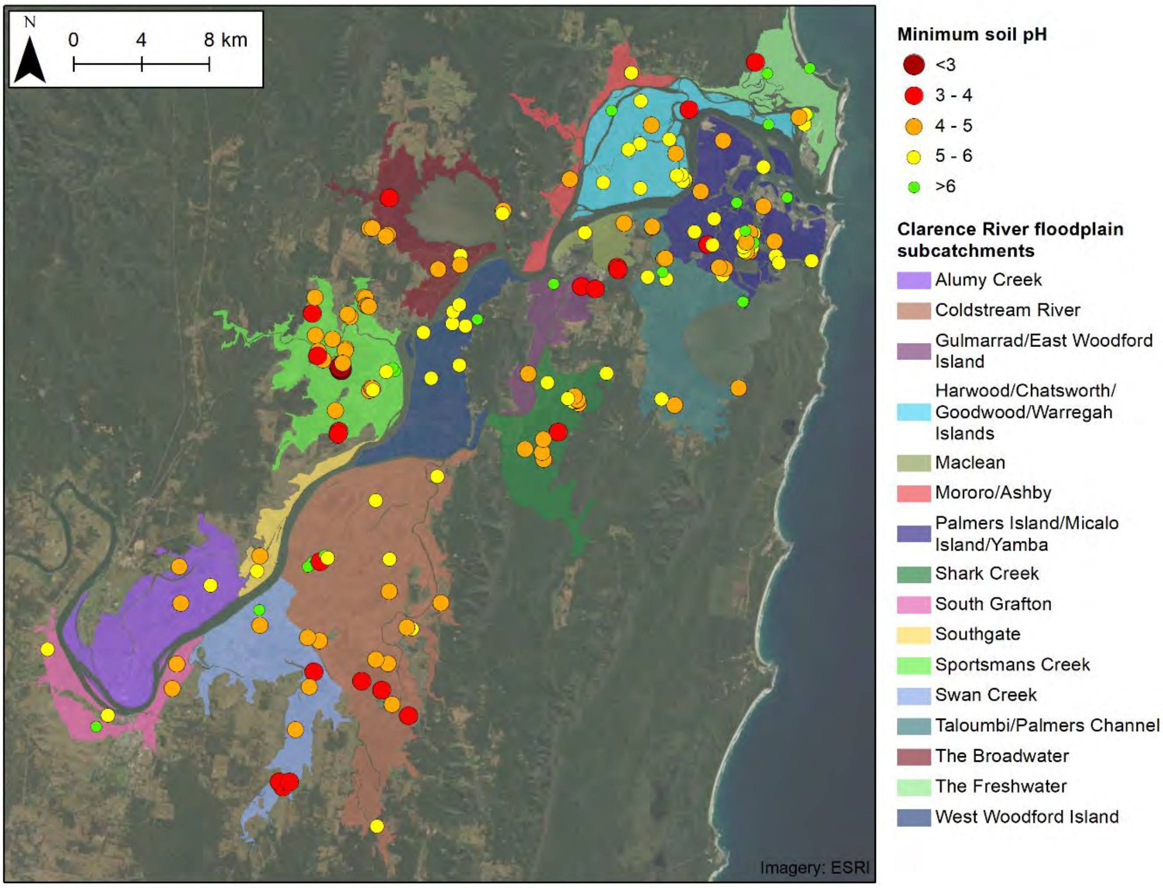

Figure 3-7: Minimum soil pH throughout the Clarence River floodplain

3.5.2 Acid discharge events in the Clarence Region

Previous fish kill events likely generated by acid discharges in the Clarence area, have been reported at Shark Creek, Chatsworth Island, Alumy Creek and Everlasting Swamp (Tulau, 1999a; Tulau, 1999b). However, compared to other catchments in NSW northern rivers, fish kill events do not appear to be as common an occurrence, possibly due to the generally high flushing ability and assimilation capacity of the Clarence River, although chronic effects of acid discharges such as red-spot disease, are more common (Tulau, 1999a; Tulau, 1999b).

Water quality monitoring throughout the Clarence River estuary has identified the presence of acid throughout the floodplain. A significant amount of those studies focused on the Everlasting Swamp system, including:

- Beveridge (1998) monitored pH values and other water parameters at 32 sites in the Everlasting Swamp, during 27 days, in 1998. Highly acidic (pH < 4) water was observed in the drains and was observed to be more common further from the Sportsmans Creek weir, due low tidal influence and little buffering capacity;
- Wilkinson (2003) collected continuous water quality data between 2001 and 2002 at multiple sites at Everlasting Swamp, upstream and downstream of Sportsmans Creek weir. Groundwater pH was observed to be most acidic at Cox Swamp (pH 3.33);

- White (2009c) assessed water quality data for Little Broadwater between April 2005 to February 2007. While the average pH was near neutral, some low pH events were observed, primarily in the southern region of the wetland; and
- Glamore et al. (2019) collected water quality data while completing fieldwork to construct a comprehensive numerical model of the Everlasting Swamp system. While the median surface water pH in this study was 6.95 across the site, acidic surface waters were observed (pH of 4) particularly in Blanches Drain.

Water quality studies across the greater Clarence River floodplain that have identified the presence of acid include:

- Woodhouse (2001a) recorded several water quality parameters over a 19 month period from 1999 at Alumy Creek, as part of a monitoring program funded by CRCC. The minimum pH at all sites measured was 5.9, however most samples were between 6.5 and 9.0;
- Wetland Care Australia (2003) collected water samples at sites in The Broadwater during drought conditions in December 2002. They found extensive surface water acidification (surface water pH as low as 2.6) and high salinity levels across the entire site; and
- Geolink (2015) monitored water quality parameters along the Pacific Highway Woolgoolga to Ballina, as part of the Environmental Impact Assessment (EIA) of surface and groundwater. Parameters were collected monthly between August 2016 and February 2020. Sites in Shark Creek sub-catchment recorded minimum surface water pH as low as 3.5. The Coldstream and Chatsworth/Harwood sites recorded minimum surface water pH values of 4.0 and 5.9, respectively.

Further information about water quality data related to ASS in the Clarence catchment can be found in Appendix H.

3.5.3 Acid sulfate soil management on sugar cane farms

While many agricultural industries have had to address the impacts of ASS and acid drainage, the sugar cane industry has been particularly active in creating formal, industry wide guidelines for ASS management. The sugar cane industry operates throughout the Northern Rivers of NSW, including on the Clarence River floodplain. Approximately 50% of sugar cane land in NSW is within areas with known occurrences of ASS (Sunshine Sugar, 2020). In 1987 mass fish kills in the Tweed River led to widespread criticism of the sugar cane industry related to the management of ASS (Beattie et al., 2001). Over the following decade, the industry took proactive steps to improve management of their soils and drainage to reduce impacts in downstream waterways. This included research, cooperation with government agencies, and the engagement of individual famers.

NSW Sugar has developed industry best practice guidelines for managing ASS on cane farms and has coordinated and participated in a number of initiatives aimed at understanding the presence and impacts of ASS (Sunshine Sugar, 2020). Note, compliance with the industry best practice guidelines has been enforced on all cane farms in NSW since a national strategy was developed in the year 2000 (White et al., 2006). The guidelines have been developed to minimise the drainage of ASS and include:

- Soil profiling of individual cane farms to confirm the presence and depth of ASS;
- Development of drainage management plans for each cane farm in NSW, including information on:
    - Depth of ASS;
    - Location and dimension of drains and how to minimises acid discharge;

    - Liming rates required when excavation is necessary; and
    - How to manage farm drainage.
- Cooperation and participation in government programs to actively manage floodgates to improve water quality and allow tidal flushing;
- Laser levelling of farms to reduce the number of drains required to provide adequate surface water drainage and minimise acidic groundwater discharges; and
- Regular auditing and reporting.

Through the development and compulsory compliance of the industry best practice guidelines, the sugar cane industry is approved to self-regulate the disturbance of ASS through normal farm practises under the relevant council LEP (Sunshine Sugar, 2020). This means that sugar cane farmers are allowed to disturb ASS material within the cane production areas of their property without prior regulatory approval, providing the disturbance is considered within their drainage management plans.

3.6 Blackwater

This section provides a brief overview of the formation and export of blackwater in coastal estuaries and blackwater runoff from Clarence River floodplain. Detailed information on the formation, export and impacts of blackwater is provided in Section 5 of the Methods report (Rayner et al., 2023).

Blackwater is a common term used to describe dark coloured waters that are characterised by high dissolved organic carbon (DOC) and reduced levels of dissolved oxygen (DO) (Moore, 1996; Moore, 2007). The discolouring of the water emanates from carbon compounds released into the water column as organic matter decays, which includes tannins (Howitt et al., 2007). Large volumes of blackwater can be generated on floodplains and are often associated with flooding, as floods act as a link between the floodplains (rich in organic matter) and the adjacent river channel (where the main impact occurs). Note, other sources of blackwater include monosulfidic black ooze (MBO) and humic blackwater. MBO and humic blackwater impact the estuary to a lesser degree in comparison to blackwater resulting from decaying organic matter (Moore, 2007). This is discussed further in Section 5 of the Methods report (Rayner et al., 2023).

Although blackwater events can be a natural part of lowland river ecosystems (Hladyz et al., 2011) and part of the floodplain carbon cycle (Wong et al., 2010b), the occurrence of blackwater events leads to low dissolved oxygen in estuarine waterways and can be fatal to fish and crustacean communities (Hladyz et al., 2011). Anthropogenic alterations to the floodplain hydrology and vegetation, mainly due to the construction of drains, flood mitigation works and swamp drainage works, have resulted in an increase in the frequency and magnitude of blackwater events (Eyre et al., 2006; Johnston et al., 2003b; Wong et al., 2010a). The construction of one-way floodgates also maintains upstream surface water levels at low tide levels (during average conditions), and enables non-water tolerant vegetation, such as pasture grasses, to establish at lower elevations where they could historically not survive (Glamore, 2003). Despite the drainage and floodgate infrastructure, these low-lying areas remain prone to inundation during flood events, and are subject to prolonged inundation due to the relatively flat gradient between backswamp areas and river water levels. Extended inundation of non-water tolerant vegetation leads to plant die off and decay, consuming oxygen from the water column, leading to the formation of low oxygen blackwater. When flood levels in the river recede, low oxygen blackwater drains into the estuary, often further consuming oxygen from the river water (Eyre et al., 2006). Where the blackwater discharges are sufficiently large to overwhelm the receiving water system, this can result in mass fish kill events (NSW DPI, 2020).

3.6.1 Blackwater runoff in the Clarence River estuary

NSW DPI (2020) maintains a record of observed fish kills across the state. The scale of the recorded events range from 'less than 10 fish' to '100,000's of fish' that have been killed per event. Fish kills can be caused by a number of processes, although acid discharge and blackwater runoff are common causes in coastal estuaries in northern NSW. It is likely that a combination of acid sulfate soil discharges, as well as blackwater from organic matter decomposition is responsible for these fish kill events.

Sixty (60) fish kill events have been recorded in the Clarence River Floodplain since 1970 (although other events are likely to have occurred but were undocumented). For the majority of these events the cause was not confirmed, although it is likely that blackwater discharges and/or acidic discharges have contributed significantly to mortality. Table 3-1 lists the most severe recorded fish kills in the Clarence River estuary, which have been in the order of thousands of fish killed at a time.

The extent of the impact caused by blackwater events in the Clarence River floodplain, has also been reported by several water quality studies, including:

- Woodhouse (2001a) recorded several water quality parameters over a 19 month period, starting from 1999 at 20 sites along Alumy Creek tributaries and drain, as part of a monitoring program funded by CRCC. Dissolved oxygen saturation levels recorded were considered extremely poor (below 85% dissolved oxygen for most of the time);
- Johnston et al. (2003b) and Johnston et al. (2005a) measured dissolved oxygen hourly between December 2000 and October 2003 at Blanches Drain (Everlasting Swamp) and also at Maloneys site (Shark Creek). For both sites, dissolved oxygen concentrations in the drains were very low from 4 to 6 days after the flood peak in February 2001, and remained relatively low (<4 mg/L) for most of the following 4 weeks;
- White (2009a) regularly sampled dissolved oxygen at Palmers Island and Wooloweyah Lagoon. Dissolved oxygen values were predominantly above 6mg/L, however some low values were recorded in Palmers Channel (2.8 mg/L) and Taloumbi drain (0.6 mg/l) after intense rainfall; and
- Rayner et al. (2016) collected pH, EC, temperature, dissolved oxygen and turbidity from surface waters at several sites in Everlasting Swamp in March 2016. Their results showed the contribution of different parts of the swamp to blackwater production. Reedy Creek and Sportsman 35/1 drain had dissolved oxygen values below <2 mg/L.

The impacts of the 2001 blackwater event in the Clarence floodplain have also been discussed by Walsh et al. (2004). Following intense rainfall and flooding, fish kills were reported between 10th and 19th of March 2001, with the largest fish kills observed in the South Arm of the Clarence River. Everlasting Swamp, Shark Creek and the Coldstream River wetlands were all identified as key contributors of blackwater in the Clarence River estuary (Walsh and Copeland, 2004).

Table 3-1: Most severe fish kills in the Clarence River estuary (NSW DPI, 2020)

Event ID	Date	River/Creek	Intensity
81	15/03/1989	Coldstream River	1,000's of fish
369	27/02/1995	Swan Creek	1,000's of fish
1049	10/02/2001	Clarence River	1,000's of fish
855	13/03/2001	Unnamed Channel/drain	1,000's of fish
856	18/03/2001	Palmers Channel	1,000's of fish
907	19/03/2001	Clarence River	1,000's of fish

Event ID	Date	River/Creek	Intensity
1127	13/07/2005	Broadmouth Creek	1,000's of fish
1431	18/01/2011	Palmers Channel, Clarence River, Shark Creek ,Coldstream	1,000's of fish
1471	6/02/2012	Clarence River	1,000's of fish
1957	19/02/2020	Alumy Creek	1,000's of fish

While water quality monitoring suggests that blackwater is generated on the Clarence River floodplain, mass fish kills appear to be observed less often and be less severe than what is observed in other large NSW estuaries. Thousands of fish were reported killed in the Clarence River during the 2001 blackwater event, however this was relatively minor compared to those reported on the Richmond River and Macleay River estuaries in the same event. Walsh et al. (2004) states that this is due to:

(i) larger river flow and buffering capacity in the Clarence River; and
(ii) the opportunity for fish to escape large water bodies in the system, including The Broadwater and Wooloweyah Lagoon.

3.7 Coastal and estuary management in the Clarence River estuary

This section provides a brief overview of the major coastal and estuary management plans and projects that have been developed for the study area. This is not intended to be a comprehensive summary of coastal and estuary management in the Clarence River estuary, but rather a summary of how these plans have acknowledged and addressed issues associated with ASS and blackwater on the floodplain.

3.7.1 NSW Marine Estate Threat and Risk Assessment (TARA) (Fletcher and Fisk, 2017)

In 2017, a state-wide threat and risk assessment (TARA) was completed to identify and prioritise threats to the environmental, social, cultural and economic benefits derived from the NSW Marine Estate (Fletcher and Fisk, 2017). This assessment found that diffuse agricultural runoff was the single highest priority threat to the environmental assets within estuaries in NSW and also present a high threat to the social, cultural and economic benefits derived from the marine estate. While diffuse agricultural runoff can relate to a wide range of water quality stressors, the TARA specifically identifies the exacerbation of acid and blackwater drainage associated with clearing riparian vegetation and artificial drainage poses a high environmental risk to estuaries throughout the state.

Based on the TARA assessment, management of acid and blackwater drainage in estuaries in NSW is considered a priority to improve environmental, social, cultural and economic benefits associated with the marine estate. This is consistent with the existing coastal and estuary management priorities in the Clarence River, discussed further in the following section.

3.7.2 Clarence Floodplain Project

The Clarence Floodplain Project (CFP) was initiated in 1997 by a steering committee comprised of members from CVC, relevant state government departments, major agricultural industries and

Aboriginal, conservation and Landcare representatives (Clarence Valley Council, 2010). The project aims included (Clarence Valley Council, 2010):

- Improving floodplain ecosystem health through restoration of natural ecosystems;
- Improving water quality and managing aquatic weeds in floodgated systems through tidal exchange;
- Improving fish habitat and passage, and reducing fish kill events;
- Reducing the impacts of ASS through increasing water tables and tidal exchange;
- Improving grazing productivity through wet pasture management on previously drained wetlands;
- Protecting and enhancing riparian and remnant vegetation; and
- Improving community involvement and engagement in natural resource management.

Through the CFP, the steering committee secured funding for a substantial amount of on-ground works within the Clarence River floodplain to address the impacts of flood mitigation infrastructure on floodplain ecosystems (Clarence Valley Council, 2020a). Funding for on-ground works were largely sourced through State and Federal Government Grants, as well as funding directly from CVC (Clarence Valley Council, 2020a).

Since 1997, the steering committee for the CFP has worked closely with local landholders to facilitate remediation of the floodplain. Individual outcomes from on-ground works as part of the CFP are discussed in the relevant subcatchment management options in Section 8, however the project has resulted in (Clarence Valley Council, 2019; Clarence Valley Council, 2020a):

- Engagement of over 250 local landholders in the active management of creeks and drains;
- Over 80 floodgates being fitted with lifting devices;
- At least 45 floodgates fitted with auto-tidal buoyancy fish gates;
- At least 21 water retention structures (weirs, or similar) installed to maintain higher water tables;
- Over 200 km of waterways opened for fish passage and tidal exchange; and
- Implementation of more than 60 drainage management plans.

3.7.3 Clarence Estuary Management Plan (Umwelt, 2003)

Umwelt (2003) completed the Clarence Estuary Management Plan with the stated aim "*to achieve a healthy, productive, attractive Clarence estuary where resources are used on a sustainable basis in harmony with environmental values, community and visitor needs*". This plan clearly identifies acid discharges from ASS (and to a lesser extent low dissolved oxygen discharges associated with blackwater) as a key issue to be addressed in the management of the floodplain.

One (1) of the key objectives identified by this study was to manage threats to ecological values in the estuary. Of particular relevance to this study, two (2) key outcomes that were recommended were to:

1. Reduce acid and low dissolved oxygen discharges in tributary creeks; and
2. Minimise blockages to fish passage, particularly in locations where removing blockages would have other benefits such as improved flushing or restoration of wetland areas.

Of the actions identified by Umwelt (2003), the recommended actions that are most relevant to this study include:

- Development and implementation of ASS management plans for areas that were identified in the Stage 1 NSW ASS Hotspot Program, including lower estuary islands (within the Taloumbi/Palmers Channel and Palmers Island/Micalo Island/Yamba subcatchments in this study), Everlasting Swamp (within the Sportsmans Creek subcatchment in this study) and Shark Creek. Other high risk ASS sites, such as Alumy Creek, were also identified as areas that should also be addressed through detailed ASS management plans. A substantial amount of on-ground works have been completed in all of these areas since this plan was written, discussed in detail in the relevant subsections of Section 8;
- Continue to implement and support the Clarence Floodplain Project (discussed in more detail in Section 3.7.2). Outcomes from this project have actively reduced the impacts of ASS and blackwater and are also discussed in detail in the relevant subsections of Section 8; and
- Completion of a trial wetland restoration project on Wooloweyah Lagoon (discussed in Section 8.6) and consider using the outcomes to encourage and incentivise restoration in other areas of the floodplain.

In addition to the actions that directly address ASS, the estuary management plan (Umwelt, 2003) also recommended improved cooperation and formalised agreements between major stakeholders (e.g. local councils, state government bodies, local landholders and industry groups) to facilitate better management of the Clarence River estuary. This is indirectly relevant to the management of ASS and blackwater as cooperation and communication between major stakeholders is often a barrier that prevents on-ground actions from occurring.

3.7.4 Coastal Zone Management Plan for Wooloweyah Lagoon (White, 2009a)

The Coastal Zone Management Plan (CZMP) for Wooloweyah Lagoon (White, 2009a) includes the main water body of Wooloweyah Lagoon, the three main estuarine waterways that connect the lagoon to the Clarence River (Palmers Channel, Micalo Channel and Oyster Channel) and the surrounding floodplains and drainage systems. The recommendations of the CZMP build on the outcomes of "Management Options for Wooloweyah Ring Drain and Palmers Channel Drainage System" (Foley and White, 2007). The lagoon is recognised for its significant ecological value and is listed on the 'Directory of Important Wetlands in Australia' and is the most important fisheries nursery habitat in the Clarence Region (White, 2009a).

White (2009a) acknowledges the presence of ASS in the Wooloweyah Lagoon region, although also states widespread acidification had not been observed in the drainage systems in numerous monitoring periods between 2002 and 2008/2009 (although high concentrations of metals were observed in the groundwater). This study indicates that the greatest risk associated with ASS in the area is through the disturbance of potential acid sulfate soils (PASS) which was already actively managed, primarily through management of floodgates to increase the water table and allow flushing. While low dissolved oxygen levels are recognised in the plan, the greatest threat to water quality in the Wooloweyah Lagoon area was stated to be high nutrients and high turbidity (White, 2009a).

Several of the management strategies recommended were relevant to this study, including:

- Regular water quality monitoring;
- Identification and prioritisation of areas for wetland remediation; and
- Improving water quality and fish habitat through management of floodgates.

Specific on-ground works that have occurred as a result of this CZMP are discussed in the management options in Section 8 in the subcatchments of Taloumbi/Palmers Channel and Palmers Island/Micalo Island/Yamba.

3.7.5 Clarence Valley Coastline Coastal Management Program (in preparation)

Clarence Valley Council and Hydrosphere Consulting are in the process of developing the "Clarence Valley Coastline Coastal Management Program" in accordance with state government legislation (Coastal Management Act 2016 and Coastal Management State Environmental Planning Policy 2018) (Clarence Valley Council, 2020b). The primary focus of the plan is the open coast beaches, but also includes the Wooloweyah Lagoon, Palmers Channel, Micalo Channel and Oyster Channel in the lower Clarence River estuary. This will replace the Coastal Zone Management Plan for Wooloweyah Lagoon (White, 2009a) once it is completed. The area covered by the scope of this upcoming plan is shown in Figure 3-8. The wider Clarence River estuary is not included in the plan. Currently, CVC and Hydrosphere Consulting are completing the first stage of the coastal management plan, the scoping study, and draft documents are not yet publicly available.

Figure 3-8: Area covered by the Clarence Valley Coastline Coastal Management Plan, included Wooloweyah Lagoon within the estuary (Clarence Valley Council, 2020b)

4 Overview of prioritisation methods

4.1 Preamble

This study prioritises coastal floodplain subcatchments based on acid discharges from ASS and blackwater runoff using an objective, evidence based method as outlined in Rayner et al. (2023). The coastal floodplain prioritisation method utilises a multi-criteria analysis approach to objectively compare the risk of acid and blackwater generation using locally acquired field evidence (including field data collected for this study). Importantly, the method is applicable to all estuarine floodplains across NSW, including the seven (7) floodplains analysed for the Coastal Floodplain Prioritisation Study. The prioritisation method used in this study does not consider improvements made through historical remediation efforts. However, any previous remediation is considered in the individual management options in Section 8. The prioritisation method used in this study does not consider improvements made through historical remediation efforts. However, any previous remediation is considered in the individual subcatchment management options in Section 8. A brief summary of these methods is provided in this section.

The prioritisation for ASS and blackwater risk within coastal floodplains is independent of one another. As such, it is possible for a subcatchment to be a low risk for ASS, but a high risk for blackwater (or vice versa). It is important to recognise that there has been no attempt to compare the prioritisation of the two issues. While a subcatchment that is ranked first for ASS can be interpreted as objectively worse for acid discharge compared to a subcatchment ranked lower for ASS, it is not also (necessarily) objectively worse than the subcatchment that ranks second for blackwater.

Both prioritisation methods have been designed to compare and rank subcatchments within an individual coastal floodplain. Therefore, the factors and subcatchment rankings in the Clarence River floodplain should not be directly compared to the prioritisation outcomes for other coastal floodplains.

4.2 Acid sulfate soil prioritisation

The ASS priority assessment undertaken for this study is an objective, benchmarked methodology used to determine the risk of acid discharges from ASS-affected estuarine floodplains in coastal NSW. The method, as developed by Glamore and Rayner (2014) and Glamore et al. (2016a), can be applied to individual drainage channels within a paddock, or across larger floodplain subcatchments. The method results in a prioritised ranking of ASS subcatchments that pose the highest risk to the ecohealth of the marine estate.

The ASS priority assessment is structured around two (2) major factors:

(i) surface water factor; and
(ii) groundwater factor.

Each factor is calculated based on local environmental processes that contribute to the risk of ASS oxidation and subsequent acid discharges to the marine estate. The risk associated with each factor is determined via a multi-criteria approach that assesses local field data and onsite environmental conditions. These factors are then combined within a calibrated algorithm to rank each subcatchment within an estuary. A summary of the risk rating, as applied to each factor, is conceptualised in Figure 4-1. Further detail on each factor is provided below.

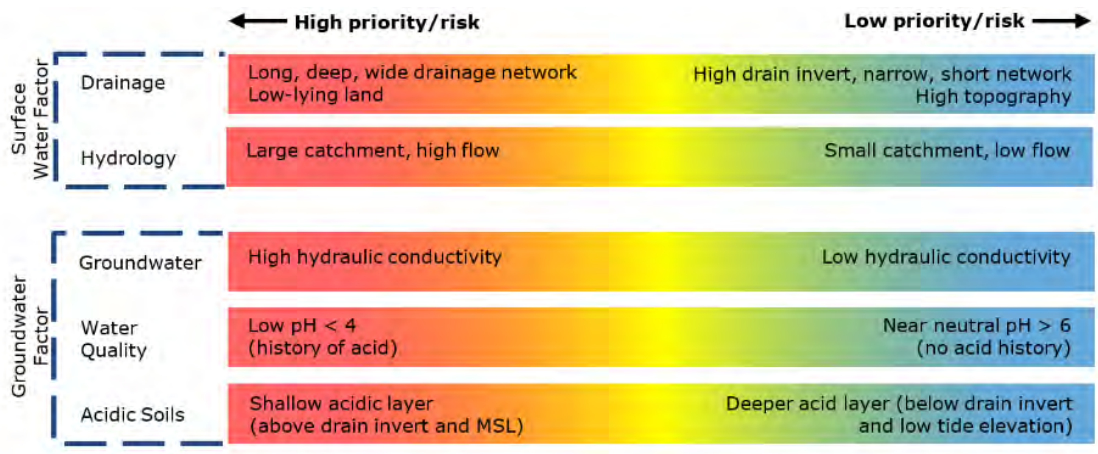

Figure 4-1: Factors influencing ASS discharge in coastal NSW that have been incorporated within the assessment method (adapted from Johnston et al. (2003a))

4.2.1 Surface water factor

Details on the calculation of the surface water factor can be found in Section 4.3 of the Methods report (Rayner et al., 2023). In summary, the surface water factor is an indication of the surface water drainage density and the catchment inflows. The surface water factor ensures that a subcatchment that is more extensively drained, or can potentially export a larger volume of acid, is ranked higher in the prioritisation method. This acknowledges that acid transport, via onsite drains and drainage flux, is a critical component towards realising acid related impacts downstream.

The surface water factor is determined by multiplying the drainage density factor by the inflow factor, as shown in Equation 4-1.

$$Surface\ water\ factor = drainage\ density\ factor\ \ x\ normalised\ inflow\ factor \qquad \textbf{Equation 4-1}$$

The drainage density factor for each subcatchment is calculated in Appendix A, while the normalised inflow factor is detailed in Appendix B.

4.2.2 Groundwater factor

The groundwater factor is designed to highlight the potential acidity that could be generated and its ability to be transported to the environment. The underpinning hypothesis is that the worst conditions are where high acidity concentrations are combined with strong groundwater transport gradients. The factor includes local information on the acidity of the sediments, the acid layer thickness, the location of the ASS layer relative to low tide levels, and the hydraulic conductivity of the sediments.

The groundwater factor uses locally acquired sediment profile data and hydraulic conductivity measurements within each subcatchment. Where existing data was insufficient, additional data was collected specifically for this project, including 49 soil profiles and 44 soil hydraulic conductivity measurements on the Clarence River floodplain (see Appendix C and D for further details). Details on the calculation of the groundwater factor can be found in Section 4.4 in the Methods report (Rayner et al., 2023).

The groundwater factor is calculated by multiplying a hydraulic conductivity risk factor by the pH factor (which accounts for the degree of acidity, acid thickness and acid layer position with respect to the lowest drain water level), as shown Equation 4-2.

$$Groundwater\ factor = hydraulic\ conductivity\ risk\ factor\ \times pH\ factor \qquad \textbf{Equation 4-2}$$

The hydraulic conductivity risk factor for each subcatchment is provided in Appendix C, while the pH factor is presented in Appendix D.

4.3 Blackwater prioritisation

The blackwater prioritisation method is independent of the ASS method and has been developed to rank subcatchments within a floodplain based on the potential for the generation of low oxygen blackwater. The blackwater prioritisation method is designed to compare blackwater risk within an estuary amongst subcatchments and is not suitable for paddock scale prioritisation due to the interconnectivity of floodplain areas during elevated flood waters. Further background on the blackwater prioritisation methods can be found in Section 6 in the Methods report (Rayner et al., 2023).

The blackwater priority assessment method is based on two (2) major factors:

(i) A contributing area of the catchment that results in blackwater production; and
(ii) The oxygen consumption risk associated with different land use and vegetation types.

These factors incorporate the key physical attributes that drive production of blackwater on coastal floodplains, discussed in detail in Section 6 of the Methods report (Rayner et al., 2023). Unlike the ASS prioritisation, the blackwater prioritisation has been undertaken with existing, catchment or statewide datasets (i.e. no subcatchment specific data was collected for this prioritisation). A summary of how each factor affects the prioritisation is provided in Figure 4-2. Note that a range of additional factors known to contribute to blackwater risk, such as temperature and antecedent conditions, were omitted from the prioritisation methodology as these variables were assumed to be (over the long term) equally applicable across the floodplain (e.g. temperature is unlikely to be significantly different within the Clarence River floodplain during a blackwater event).

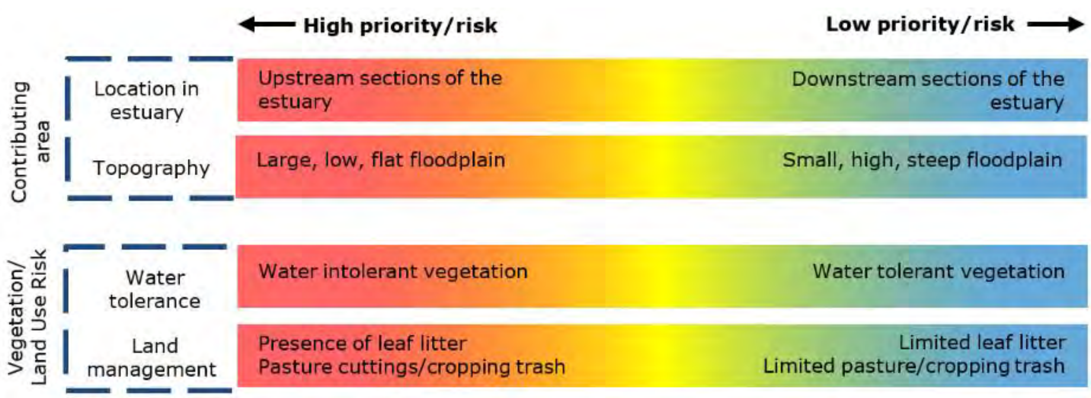

Figure 4-2: Factors influencing blackwater discharge within a coastal floodplain in NSW

4.3.1 Contributing blackwater area

The calculation of the contributing blackwater area is based on the topography of the floodplain subcatchment and an analysis of historical water level observations within the estuary to determine observed inundation frequency and duration. Since hypoxic blackwater is generated when water intolerant vegetation is inundated over an extended period, the risk of blackwater generation is greater in areas that are prone to prolonged inundation.

Long-term water levels in the main river channel were analysed to establish 25 water level thresholds relating to different periods of river water elevation (e.g. elevated over a given threshold for 1, 2, 3, 4 or 5 days) and temporal frequencies (e.g. 1, 2, 3, 4 or 5 year return intervals). Water levels in the main river channel were then projected across the adjacent floodplain subcatchments using a geospatial approach to identify areas likely to be subject to reduced drainage and prolonged inundation. These areas were identified as key contributors to blackwater generation under different flood events and flood behaviour. Appendix E provides the details of this analysis within the Clarence River estuary and floodplain. While 25 water level thresholds are used in this analysis, a median elevation has been adopted throughout this report to provide an indicative elevation for blackwater contribution in each floodplain subcatchment.

4.3.2 Land use/vegetation risk factor

Water tolerance varies between different vegetation types, with some vegetation having a higher ability to decompose, leading to a greater risk of blackwater generation. To account for differences in land use and associated vegetation types, a summary risk rating was developed. While details of the risk rating associated with all land use types can be found in Section 6.3 of the Methods report (Rayner et al., 2023), the following general rules have been applied:

- High: Areas used for grazing, forestry, perennial horticulture (such as macadamia farming);
- Moderate: Areas used for cropping, particularly sugar cane, are moderate risk; and
- Low: Areas that are predominantly covered by water tolerant vegetation (e.g. marshes or wetlands) present the lowest risk.

Areas that have been mapped as macrophytes by DPI Fisheries (2019) or as open water bodies have been excluded from contributing to blackwater risk. The land use risk factor has been combined with the contributing area factor to calculate the final blackwater risk ranking for each subcatchment. This ranking identifies areas that pose the greatest risk of blackwater generation. It is worth noting that this ranking does not consider risks to downstream sensitive receivers or to the assimilation capacity of the downstream waterway.

5 ASS prioritisation assessment outcomes

5.1 Preamble

This section summarises the results of the ASS priority assessment for the Clarence River floodplain. The summary rankings and acid prioritisation factors for each of the subcatchments are provided in Section 5.2. The final rankings in the ASS priority assessment are a function of a surface water drainage factor and a groundwater factor calculated for each subcatchment, as discussed in Section 4 and Appendices A - D. The highest priority subcatchments have the highest combination of the surface water and groundwater factors, thereby presenting the highest risk of acid drainage.

The prioritisation method used in this study does not consider improvements made through historical remediation efforts. However, any previous remediation is considered in the subcatchment management options in Section 8. Similarly, the prioritisation method does not consider the assimilation capacity of the river (the ability of the river to dilute or neutralise pollutants), or the presence of sensitive receivers. However, both have been considered management options in Section 8.

5.2 ASS prioritisation of the Clarence River floodplain

A summary of the catchment wide ASS prioritisation is provided in Table 5-1 and presented in Figure 5-1 to Figure 5-3. The top priority subcatchment identified was the Sportsmans Creek subcatchment, which is well recognised as an ASS hotspot (Beveridge, 1998; Glamore et al., 2019; Tulau, 1999a). The top five (5) priority subcatchments span across the Clarence River floodplain, which shows that impacts from acid drainage on aquatic habitat (identified in Appendix J) can occur throughout the estuary.

Table 5-1: Summary results and rankings of ASS subcatchments in the Clarence River floodplain

Subcatchment	Groundwater Factor	Surface Water Factor	Final Acid Factor	Rank
Sportsmans Creek	51	1,666	85,550	1
Swan Creek	157	299	46,864	2
Gulmarrad/East Woodford Island	174	162	28,206	3
Shark Creek	142	162	23,030	4
Taloumbi/Palmers Channel	27	525	14,156	5
Coldstream River	58	198	11,572	6
Mororo/Ashby	23	484	10,925	7
The Broadwater	76	93	7,034	8
Maclean	71	50	3,526	9
Harwood/Chatsworth/Goodwood/Warregah Islands	15	183	2,740	10
Palmers Island/Micalo Island/Yamba	9	259	2,347	11
South Grafton	12	159	1,870	12
West Woodford Island	5	308	1,565	13
Alumy Creek	16	73	1,148	14
Southgate	11	42	469	15
The Freshwater	25	11	263	16

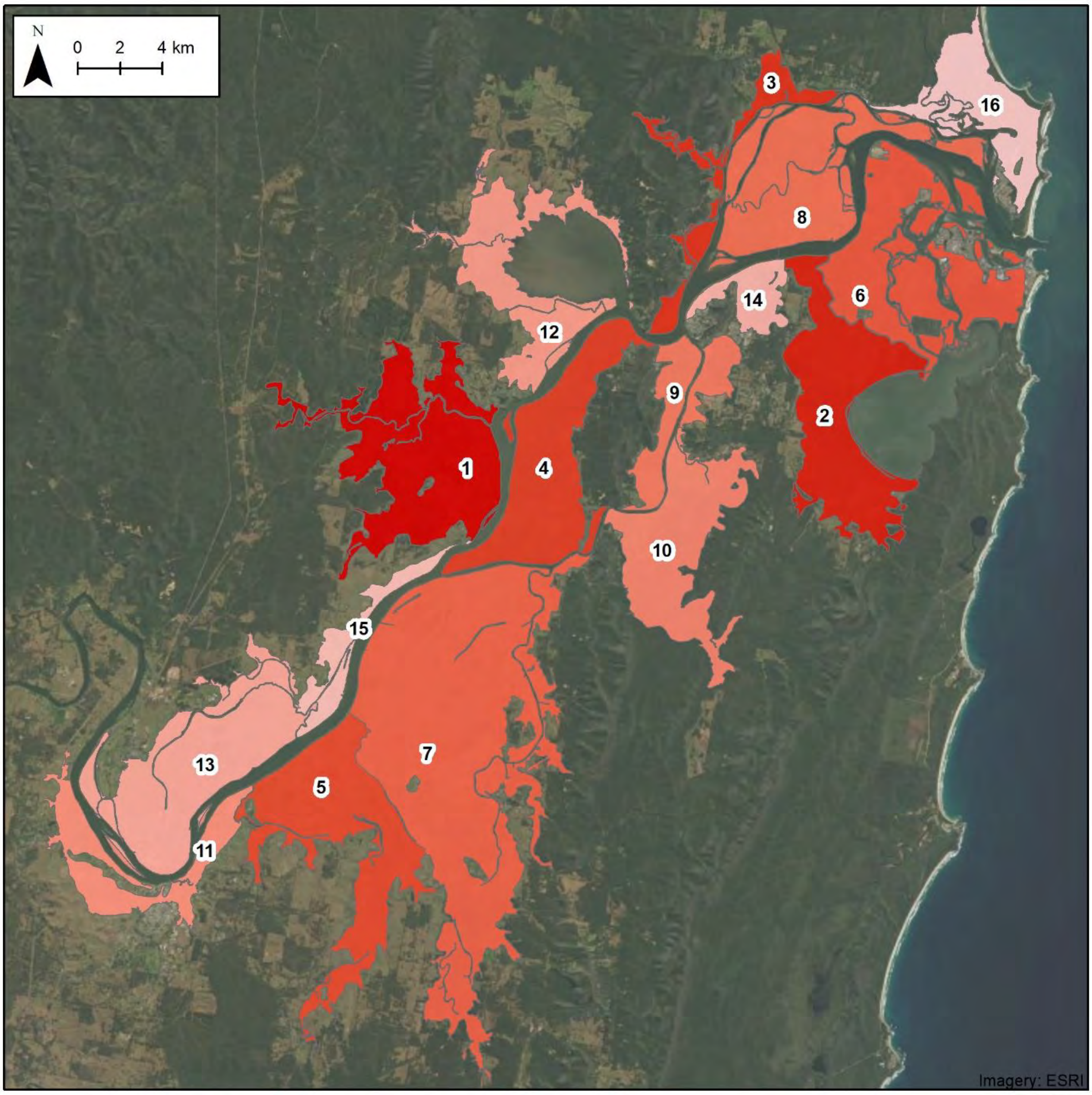

Figure 5-1: Surface water factor ranking

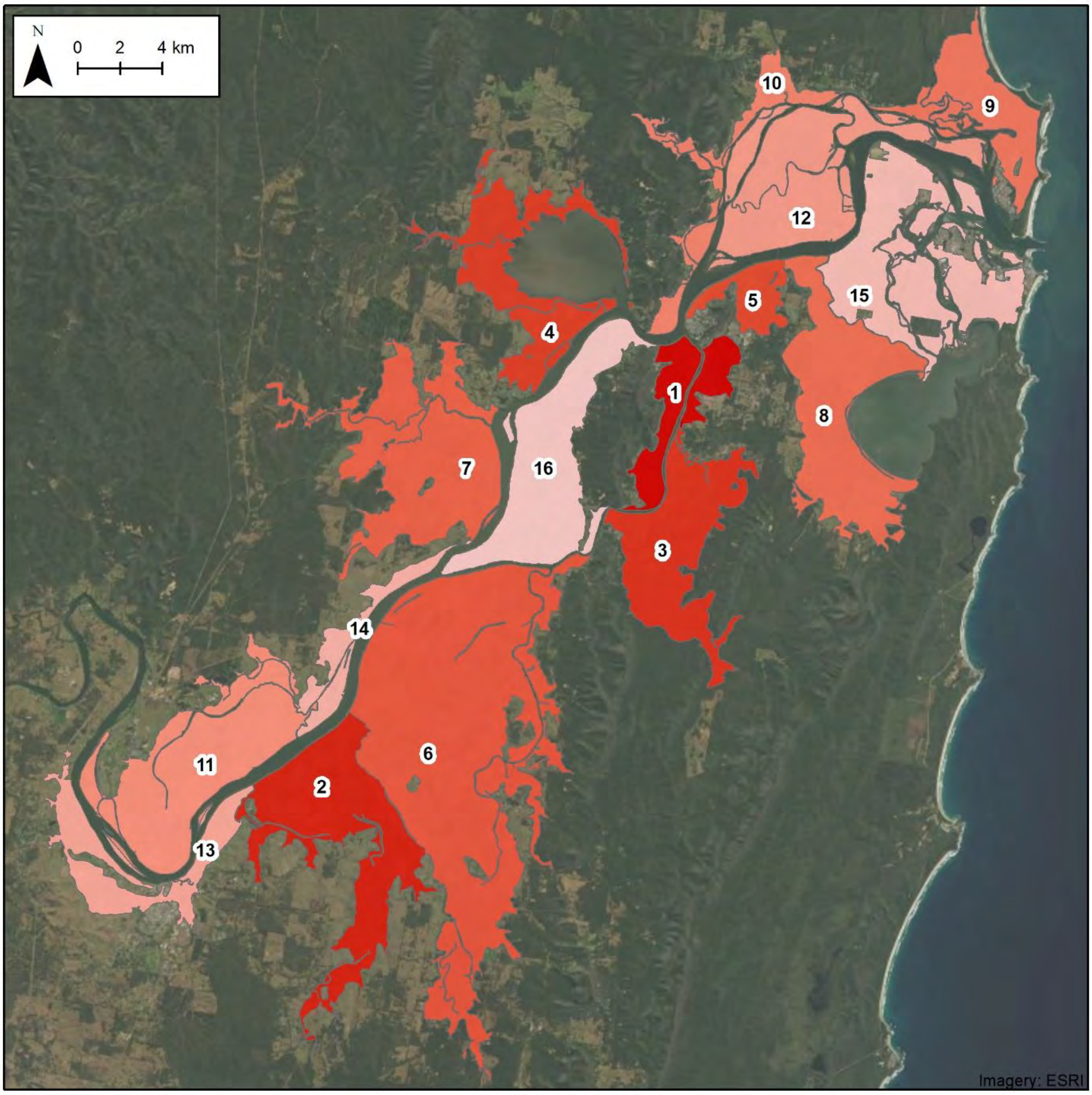

Figure 5-2: Groundwater factor ranking

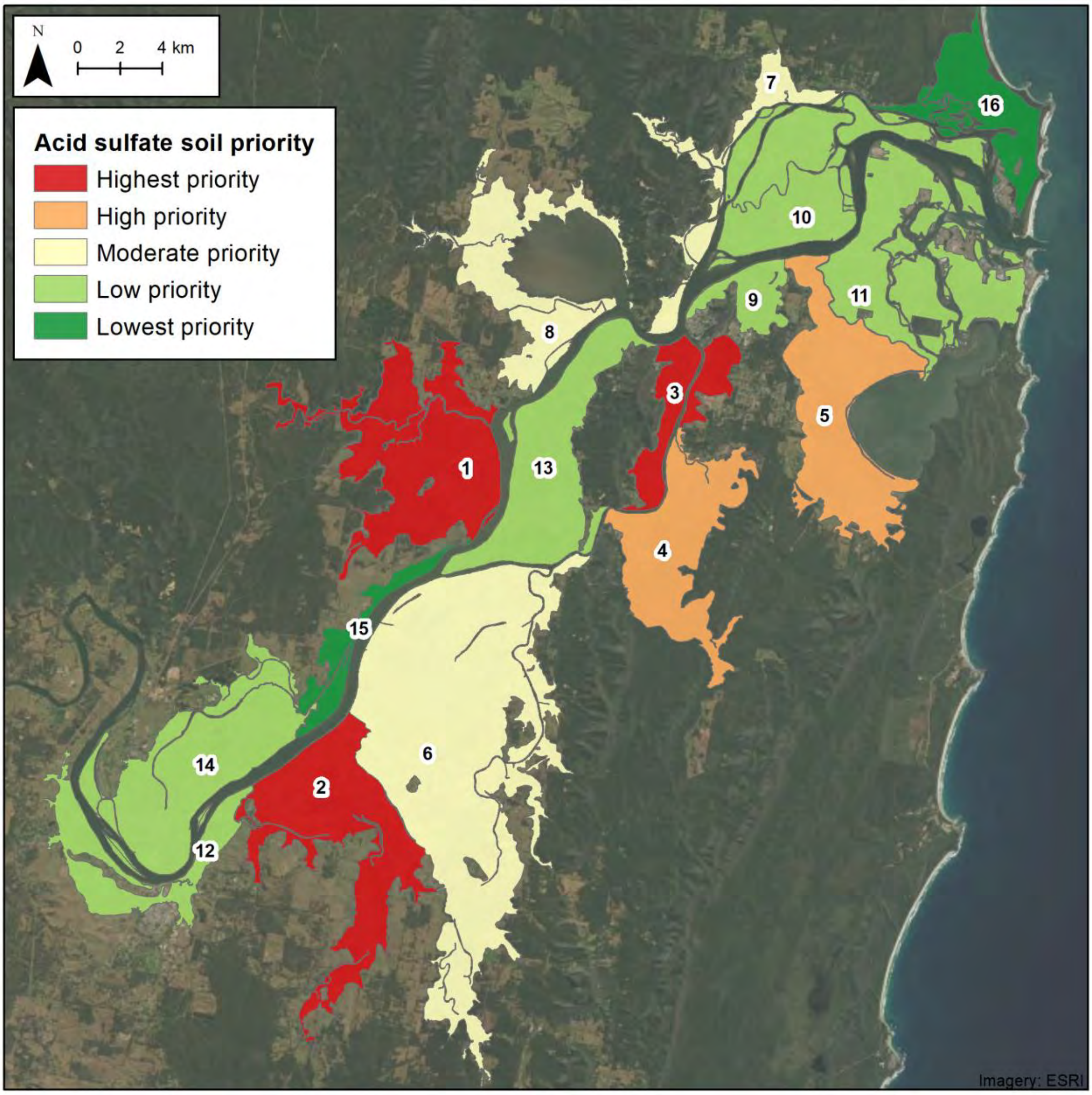

Figure 5-3: Final ranking of ASS prioritisation

6 Blackwater prioritisation assessment outcomes

6.1 Preamble

This section summarises the results of the blackwater priority assessment on the Clarence River floodplain. The overall rankings and calculated prioritisation factors that contribute to the ranking of each subcatchment are provided in Section 6.2. The final rankings in the blackwater prioritisation are a function of elevation and land use factors. A summary of the elevations used to calculate the blackwater contributing area on floodplain subcatchments is provided in Appendix E.

6.2 Blackwater prioritisation of the Clarence River floodplain

A summary of blackwater prioritisation is provided in Table 6-1 and presented in Figure 6-1 and Figure 6-2. The top priority catchment, the Coldstream River, has a substantially higher blackwater factor than any other subcatchment. Figure 6-2 shows that the top four (4) subcatchments are distributed across the floodplain.

Table 6-1: Final results and rankings of the blackwater priority assessment for the Clarence River floodplain

Subcatchment	Median blackwater elevation (m AHD)	Final blackwater factor	Rank
Coldstream River	1.9	153.5	1
Sportsmans Creek	1.9	99.3	2
Swan Creek	1.9	62.1	3
Taloumbi/Palmers Channel	0.9	52.2	4
Shark Creek	1.1	43.1	5
West Woodford Island	1.6	32.9	6
Alumy Creek	2.1	32.9	7
The Broadwater	1.3	25.3	8
Harwood/Chatsworth/Goodwood/ Warregah Islands	0.9	20.0	9
Gulmarrad/East Woodford Island	0.9	12.2	10
South Grafton	1.5	11.6	11
Southgate	1.8	10.7	12
Maclean	0.9	10.3	13
Palmers Island/Micalo Island/Yamba	0.5*	9.2	14
Mororo/Ashby	0.9	8.4	15
The Freshwater	0.9	7.0	16

*Mean high water elevation. See Appendix E for details.

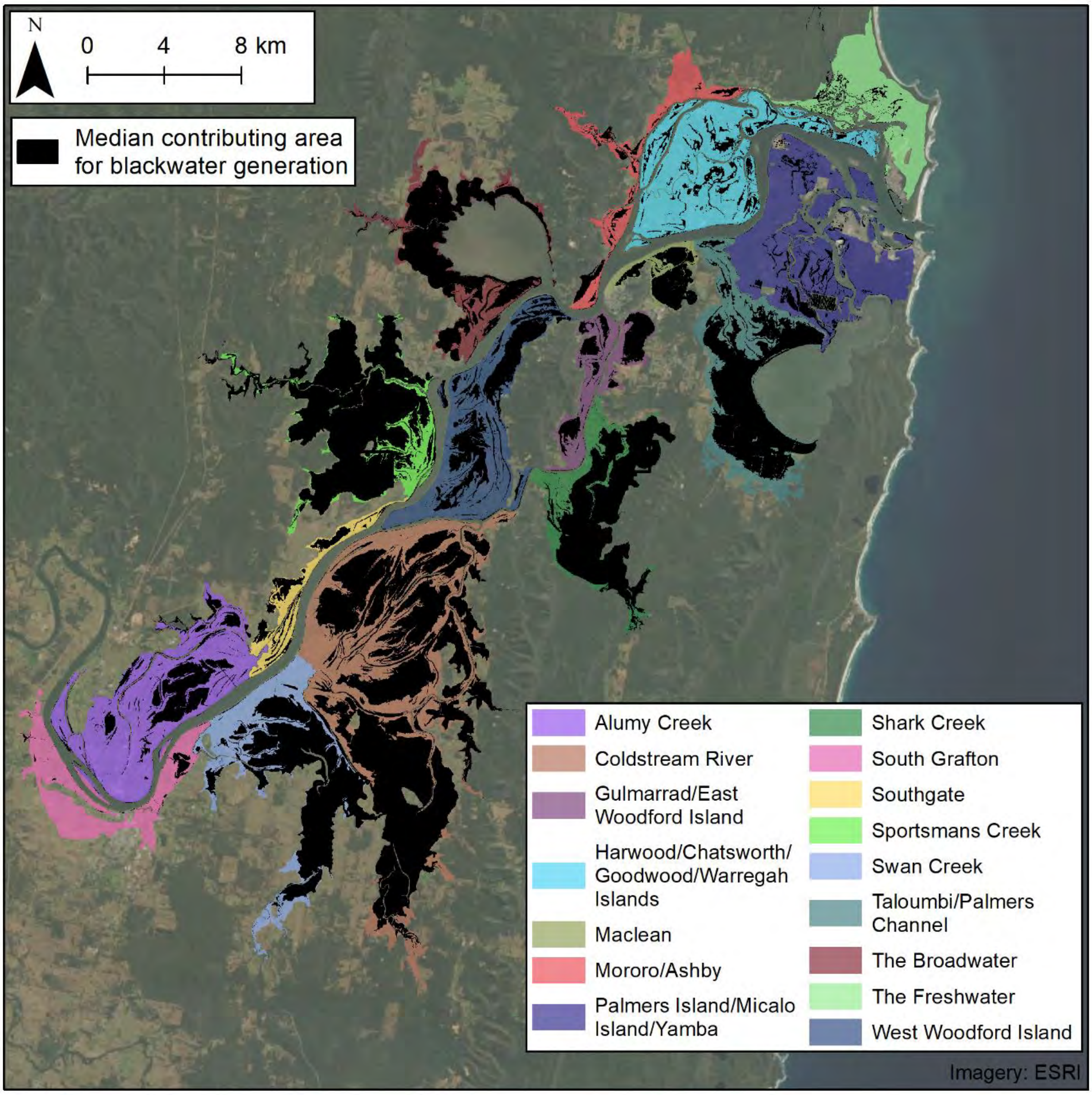

Figure 6-1: Median contributing area for blackwater generation across the Clarence River floodplain

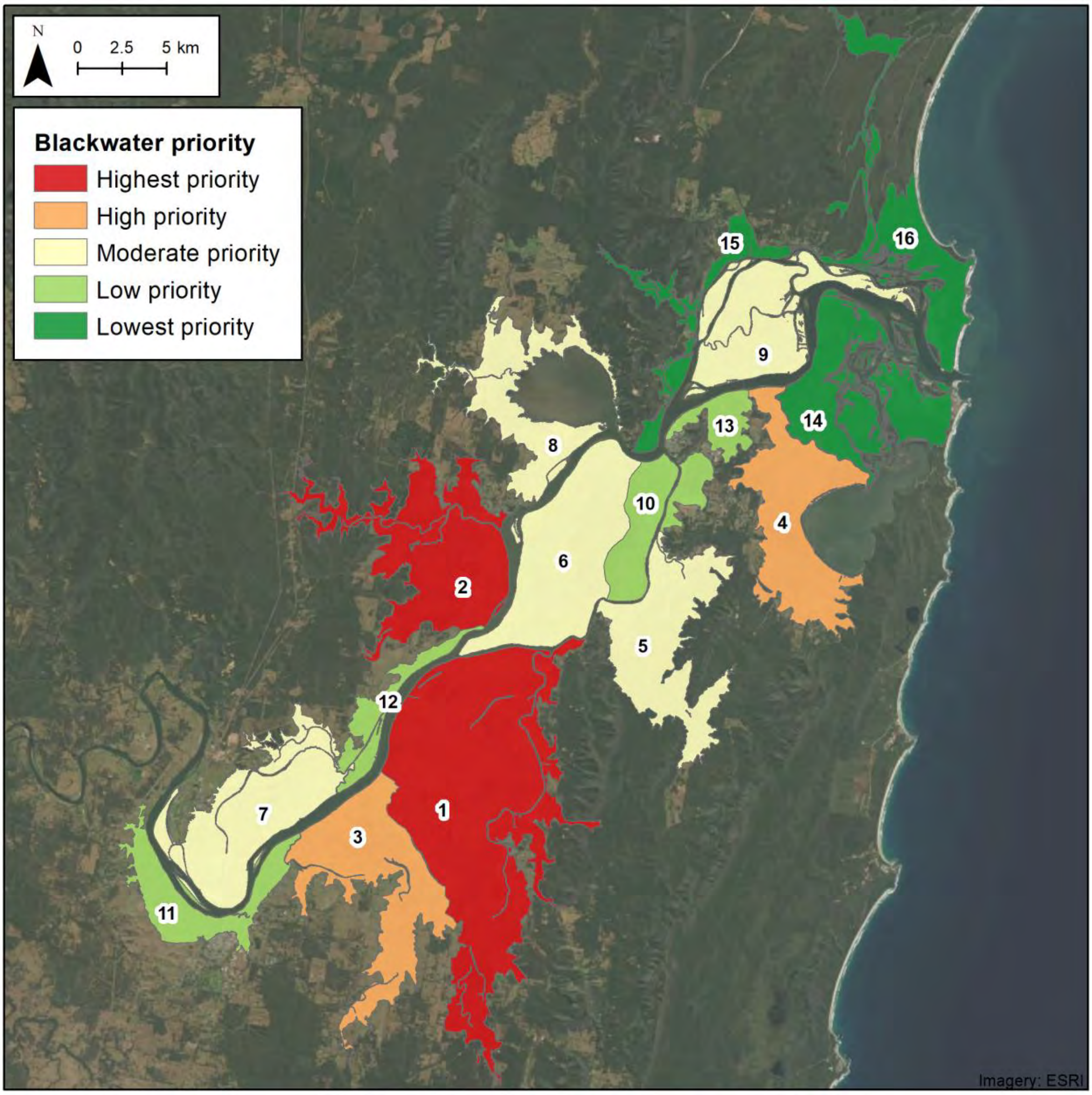

Figure 6-2: Final ranking of the blackwater prioritisation in the Clarence River floodplain

7 Sea level rise implications

7.1 Preamble

White et al. (2014) completed an analysis of tidal gauges across Australia and found that the average rate of rise in relative sea levels between 1966 – 2010 in Australia was +1.4 mm/year and had accelerated to +4.5 mm/year across the country between 1993 - 2010. The rate of sea level rise is expected to continue to accelerate over the next century (IPCC, 2014). Coastal estuaries are amongst the most vulnerable areas to sea level rise due to the proximity to the ocean and level of development in Australian estuaries (OEH, 2018).

Coastal floodplains are susceptible to sea level rise as changes in sea levels and hence tidal levels, will intensify factors that currently contribute to flooding, reduced drainage efficiency, and inundation extent/duration. The following section summarises the assessment completed for this study to identify floodplain areas and floodplain infrastructure in the Clarence River floodplain that are vulnerable to future sea level rise. Detailed information on how climate change will likely influence estuaries in NSW can be found at: http://estuaries.wrl.unsw.edu.au/index.php/climate-change/ (accessed 23/09/2020).

Note, acid and blackwater generation and drainage are intrinsically linked to water levels in the main estuary and will be affected by sea level rise. Sea level rise will likely reduce the impact of ASS discharges in estuaries, due to (but not limited to):

- Greater neutralisation capacity (through natural bicarbonates available in sea water) of the mid-upper estuary associated with greater penetration of the tide; and
- Reduced groundwater drainage due to higher average surface water levels throughout the drainage network.

The impact of sea level rise on blackwater drainage is less well understood and dependent on a number of factors. In the short-term, proliferation of non-water tolerant vegetation across the floodplain will likely result in an increased blackwater risk as a result of greater and more frequent flooding due to sea level rise. However, in the long-term, sea level rise will result in reduced drainage and prolonged inundation across the floodplain. This will mean it is likely for water tolerant vegetation to grow and establish in areas susceptible to reduced drainage, reducing the potential for blackwater generation. More research is required to model the likely changes in acid and blackwater drainage in NSW estuaries under future sea levels.

7.2 Changes to tides in estuaries

Glamore et al. (2016b) detailed how water levels in estuaries are influenced by oceanic forces and climate change. In brief, tidal water levels at the entrance of an estuary influence the overall volume of water (tidal prism) moving in and out with each tide. The tidal prism, the channel bed friction, catchment inflows and the channel geometry (i.e. the depth and the shape of the estuary) influence whether tide levels amplify (increase), remain constant or attenuate (decrease) as the tide travels upstream. With sea level rise, tidal levels at the entrance of an estuary will increase, but as described above, the impact on tidal water levels within the estuary is dynamic and non-linear, and therefore not intuitively relatable to the sea level rise changes in the ocean.

Numerical models enable the behaviour and response of estuaries to sea level rise to be investigated. Section 11 of the Methods report (Rayner et al., 2023) discusses the different types of numerical models and their merit for use in dynamic estuarine systems. For this study, a hydrodynamic numerical model was constructed of the Clarence River estuary, and calibrated to present day tidal levels throughout the estuary. The tidal levels at the oceanic boundary of the estuary were then altered to predict the impact of sea level rise throughout the estuary. The aim of the numerical modelling analysis was to establish water level statistics for past, present-day, near future and far future planning horizons throughout the Clarence River estuary and detail hydrodynamic processes such as tidal attenuation and amplification.

The following section outlines the numerical modelling approach used to investigate sea level rise in the Clarence River estuary. Further details on the model development and calibration can be found in Appendix I.

7.2.1 Clarence River estuary hydrodynamic model

A hydrodynamic model was constructed using the finite element model RMA-2 (King, 2015) to simulate the tidal currents and freshwater inflows to the Clarence River estuary. The model domain, shown in Figure 7-1 extends across the tidal region of the Clarence River and its tributaries, including: Cold Stream River, Sportsman Creek, Esk River, North Arm, South Arm, the Broadwater, the Back Channel, Oyster Channel, Palmers Channel and Wooloweyah Lagoon. The numerical model was constructed using a combination of one dimensional (1-D) and two dimensional (2-D) elements. 1-D elements were used in areas where flow occurs perpendicular to the cross section and 2-D elements were used to represent the lower estuary where complex free surface flows occur (i.e. where the flow can occur in both the x-y plane).

The model was developed to ensure coverage of the areas of interest (i.e. major floodgate infrastructure) in the lower estuary and extends up to the tidal limit (approximately 106 km from the entrance) near Sealands. The hydrodynamic model comprised of three (3) main inputs:

1. **Channel bathymetry and geometry**, based on the previous modelling of the Clarence River (Glamore et al., 2014) and updated with the bathymetry from the most recent hydrographic survey through Oyster Channel and Wooloweyah Lagoon undertaken by WRL in June 2020;
2. **Downstream tidal water levels** applied at the downstream ocean boundary. This was based on the observed records from the Manly Hydraulics Laboratory water level station at Yamba (Station # 204454); and
3. **Upstream river flow** applied as inflow hydrographs at the upstream extent of the model at the junction near Whiteman Creek. This data was sourced from the WaterNSW river gauge at Clarence River at Lilydale (Station # 204007).

Figure 7-1: Clarence River estuary hydrodynamic model extent

Lower catchment floodplain inflows were not included as sensitivity testing indicated that floodplain runoff has a relatively small impact on the day-to-day water levels in the lower Clarence River estuary (which is dominated by the downstream tide). As such, the resulting hydrodynamic model is calibrated for everyday tides, but is not suitable to replicate catchment flood events. This is considered to be appropriate as the hydrodynamic model has been used in this study as a tool to assess the vulnerability of end of system drainage infrastructure and floodplains to changes in day-to-day drainage due to sea level rise, rather than large-scale catchment flood events. Further information on the hydrodynamic model setup and calibration are provided in Appendix I.

The hydrodynamic model for the Clarence River estuary was calibrated to selected water level and tidal flow gauging stations for 1996. The year 1996 was selected based on short-term tidal flow gauging of the Clarence Estuary which were recorded at various locations within the estuary on 24 October 1996 (MHL, 1996). The locations of tidal flow gauging sites and water level monitoring stations used for calibration are provided in Appendix I. The calibrated model was then used to simulate a representative ‘wet’ year (i.e. more rain than average across the catchment) and a representative ‘dry’ year (i.e. less rain than average across the catchment) based on analysis of rainfall records in Northern NSW. For this project, 2013 and 2019 were selected as the wet and dry years respectively, based on long term rainfall monitoring by the Bureau of Meteorology.

7.2.2 Historic and future sea level rise

Four time periods have been identified to simulate how sea level rise influences estuarine water levels:

- A historic scenario (HS) (~1960);
- Present day (PD (~2020);

- Near future (NF) (~2050); and
- Far future (FF) (~2100).

Sea level rise scenarios were based on scenarios from Glamore et al. (2016b). The adopted changes in mean sea level relative to 2020 for these periods have been detailed in Section 11 of the Methods report (Rayner et al., 2023) and are provided in Table 7-1.

Freshwater catchment inflows were not modified to account for changes to rainfall and catchment run-off as a result of climate change. Global climate models typically cannot resolve hydrological processes (i.e. catchment rainfall and runoff) with sufficient detail. The NSW and ACT Regional Climate Modelling (NARCliM) Project is a regional climate model ensemble (containing 12 individual models) that provides high resolution (10 x 10 km) climate projections for wider NSW. Heimhuber et al. (2019a) analysed the results from NARCliM modelling for near future and far future scenarios and found that rainfall is expected to stay largely the same in terms of annual totals along the NSW coast (albeit with some statistical uncertainty).

In a recent study undertaken by Nguyen et al. (2020) it was shown that mean annual streamflow is expected to reduce by -20% to -30% for most catchments by the end of the century largely due to increased evaporation resulting from increased temperatures. This may result in an increase in tidal influence in the upper sections of the estuary, but is unlikely to influence estuary wide water levels as significantly as sea level rise and has therefore not been included in modelling for this study. The results of the modelling in this study should be seen as a 'first-pass' assessment of sea level rise impacts on the Clarence River estuary.

Table 7-1: Adopted mean sea level relative to present-day (2020)

Time period	Adopted change in mean sea level relative to 2020 (m)
HS - Historical (circa 1960)	-0.05
PD - Present day (circa 2020)	0
NF - Near future (circa 2050)	+0.16
FF - Far future (circa 2100)	+0.67

7.3 Water level statistics

The hydrodynamic models were run for two (2) years for each of the four (4) sea level rise scenarios (Table 7-1). Water levels were extracted at the locations of interest and statistical analysis used to assess potential floodplain vulnerability. Increasing water levels, particularly higher low tide levels, will significantly impact the drainage potential (i.e. hydraulic gradient) of coastal floodplains.

Three (3) main statistical water levels have been used to assess floodplain vulnerability:

- **5th percentile water level** (water levels are below this level 5% of the time, or around 1 hour a day) – this represents a low tide water level at a given location. Areas below the 5th percentile water level are typically permanently inundated and difficult to drain without additional mechanical assistance (i.e. pumping);

- **50th percentile water level** (water levels are above/below this level 50% of the time) – this is a median water level. Areas below the 50th percentile water level can be difficult to drain efficiently, although the use of one-way floodgates has allowed agricultural development on low-lying land; and
- **95th percentile water level (**water levels are below this level 95% of the time, or around 23 hours a day) – this represents a high tide water level at a given location. While these areas are commonly used for agriculture, areas below the 95th percentile water level may be impacted by reduced drainage, particularly after flood events.

7.4 Floodgate vulnerability

Tidal floodgates are used extensively throughout the Clarence River estuary to mitigate backwater flooding from the river, prohibit tidal water from inundating low areas of the floodplain, and encourage regular tidal drainage to the low tide level upstream of the floodgate. The vulnerability of a floodgate to potential reduced flow efficiency due to sea level rise can be identified by determining how frequently the floodgates are able to freely drain based on the downstream water levels and the floodgate geometry/elevation. Table 7-2 summarises the classifications applied to each floodgate. This is also presented diagrammatically in Figure 7-2. The approach to assessing floodgate vulnerability is discussed further in Section 11 of the Methods report (Rayner et al., 2023) .

Table 7-2: Rules for floodgate vulnerability classification

Colour	Classification	Criteria
Green	Least Vulnerable	Obvert > 95th percentile water level
Orange	Moderately Vulnerable	95th percentile water level > Obvert > 50th percentile water level
Red	Most Vulnerable	Obvert < 50th percentile water level

Note: Obvert is the inside top of the floodgate structure

The classification identifies floodgates that will not allow efficient drainage of surface water (either now or into the future). Based on this classification, a floodgate is classified as:

- 'Least Vulnerable' if the structure can drain effectively for at least 95% of the time (approximately 23 hours in a day) (Figure 7-2a);
- 'Moderately Vulnerable' if the structure can drain effectively between 50% – 95% of the time (i.e. between 12 to 23 hours of the day) (Figure 7-2b); and
- 'Most Vulnerable' if the structure can drain effectively for less than 50% of the time (i.e. for less than 12 hours of the day) (Figure 7-2c).

The floodgate vulnerability assessment was completed by comparing the floodgate obvert elevations to the downstream water levels statistics (i.e. the simulated water levels from the nearest numerical model node). Water level statistics were extracted for the historic (HS), present day (PD), near future (NF) and far future (FF) simulations for the 5th, 50th and 95th percentile exceedances and compared to the floodgate elevation. Note that the floodgate vulnerability assessment could only be applied to tidal floodgates at the end of the drainage system, where the drainage system discharges into the estuary and where infrastructure survey data was available.

Figure 7-3 to Figure 7-6 present floodgate vulnerability maps for the Clarence River estuary for the scenarios tested. Detailed mapping for each floodplain subcatchment is provided in Section 8. This assessment does not consider the design life of floodplain infrastructure or the additional vulnerability expected from aging infrastructure and has been completed only considering present day floodgate geometry. A significant portion of the infrastructure considered is likely to require substantial capital expenditure to maintain functionality over the next century, regardless of changes to sea levels.

Table 7-3 presents a summary of the number of floodgates which are classified as 'Most Vulnerable', 'Moderately Vulnerable' and 'Least Vulnerable' for each of the simulated scenarios. By the far future, 165 of 375 (44%) floodgates with known elevation are considered "Most Vulnerable", compared to just 27 (7%) in present day conditions. As shown in Figure 7-5 and Figure 7-6, the lower estuary has a higher proportion of floodgate infrastructure that is identified as moderate to high vulnerability, compared with the upper estuary.

Table 7-3: Vulnerability classification of Clarence River floodplain floodgates

Floodgate Vulnerability	Historic Scenario (HS) ~1960	Present Day (PD) 2020	Near Future (NF) ~2050	Far Future (FF) ~2100
Least Vulnerable	290	262	227	132
Moderately Vulnerable	66	86	101	78
Most Vulnerable	19	27	47	165

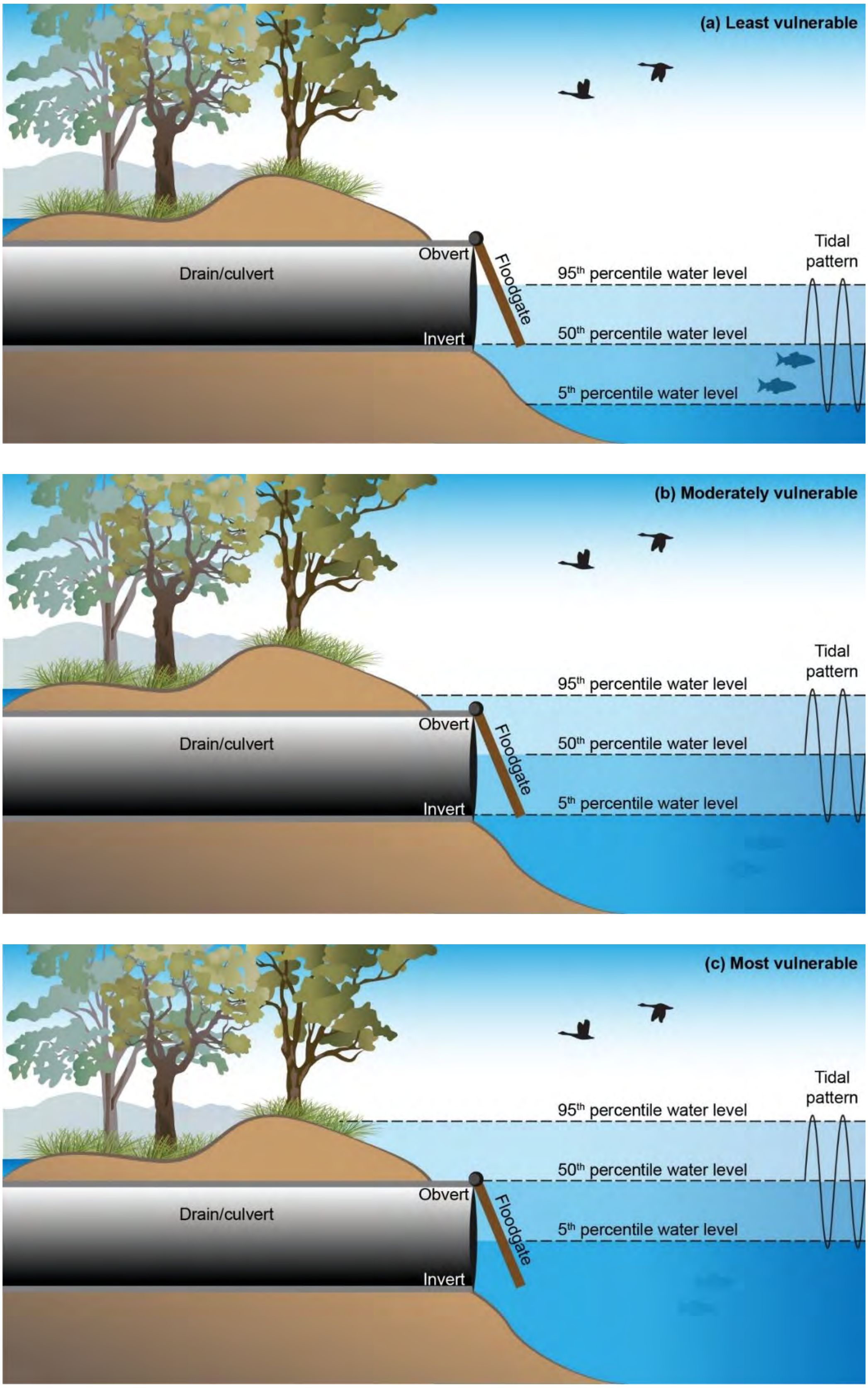

Figure 7-2: Floodgate vulnerability assessment

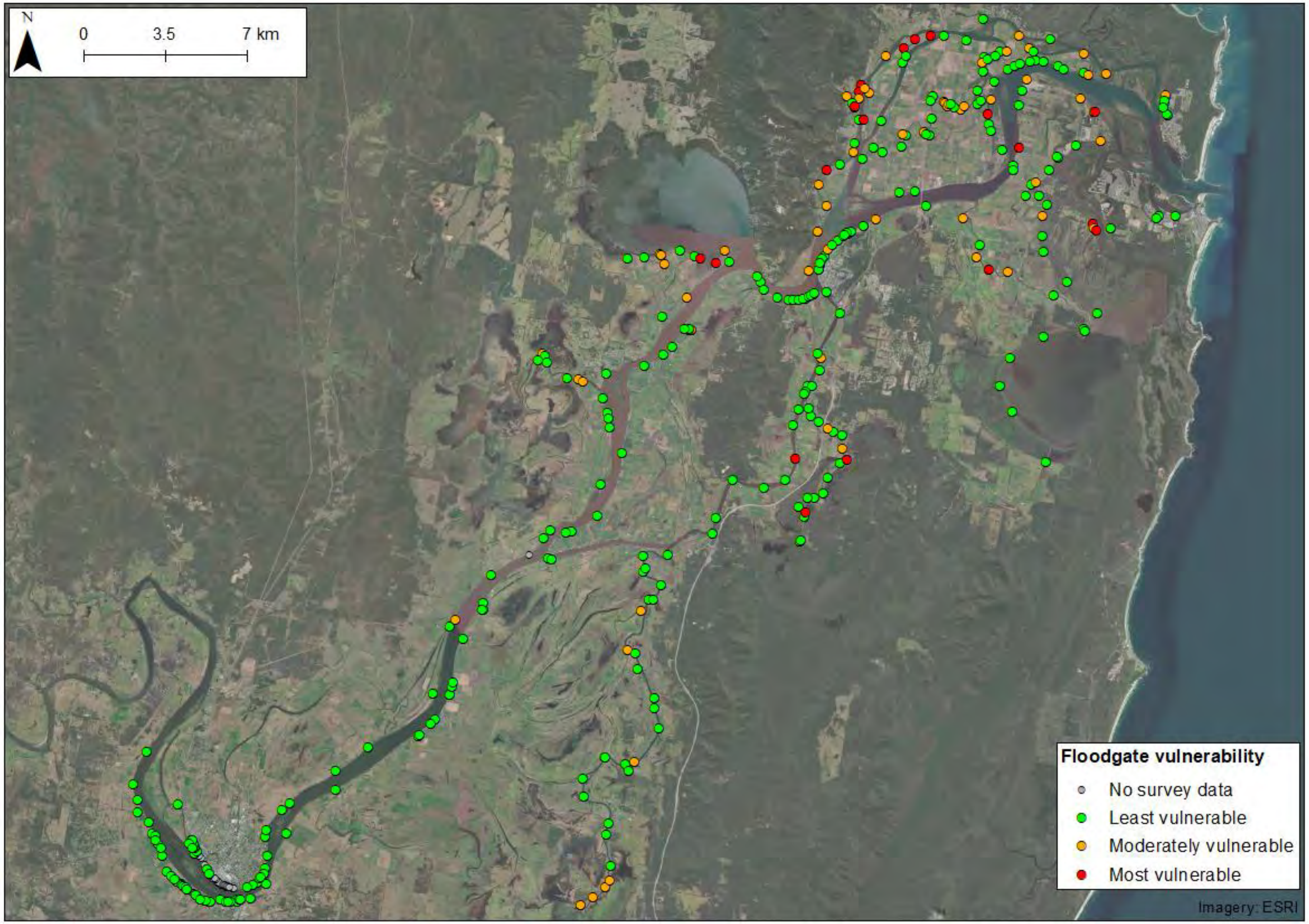

Figure 7-3: Historic (~1960s) floodgate vulnerability – Clarence River estuary

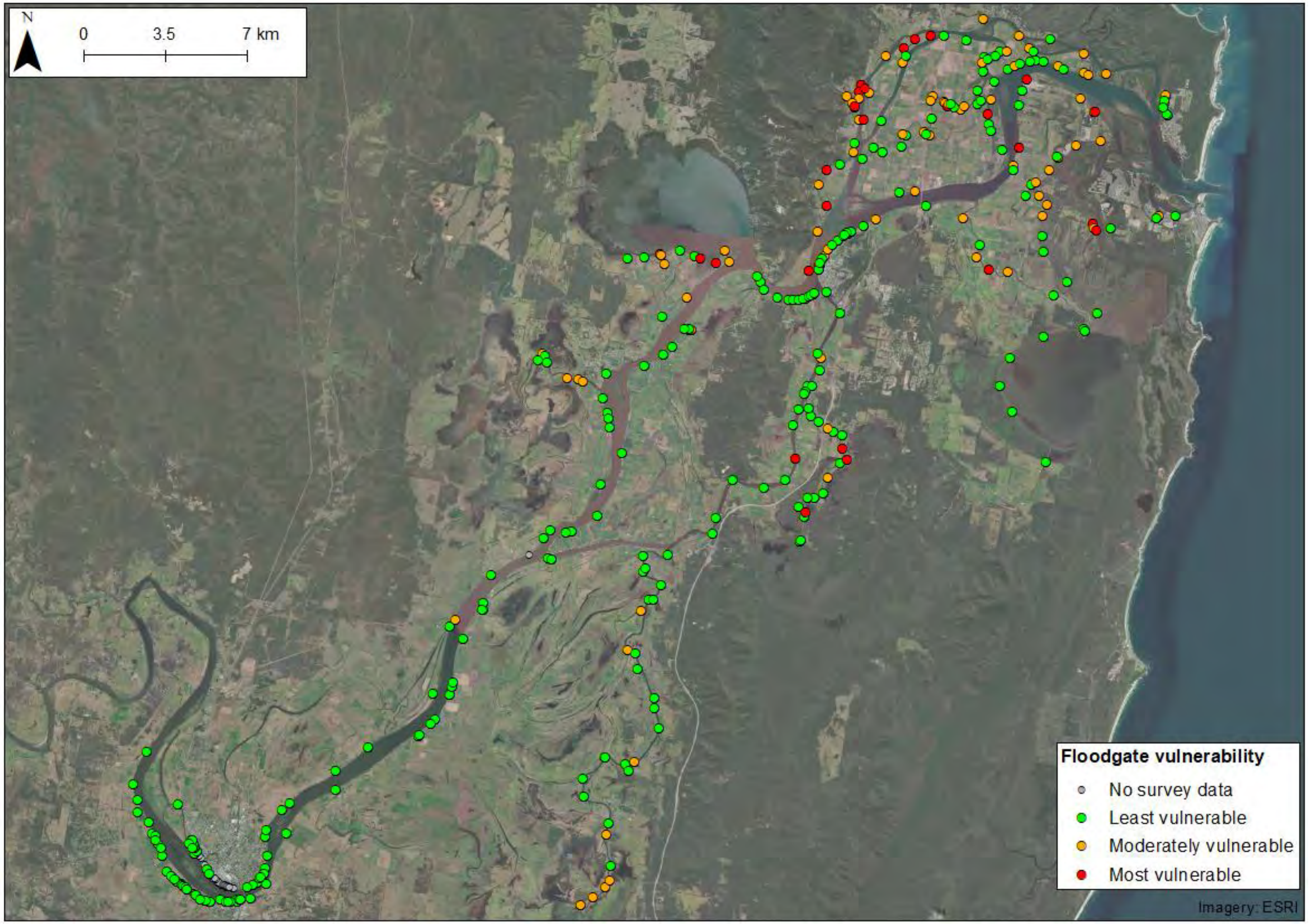

Figure 7-4: Present day (2020) floodgate vulnerability – Clarence River estuary

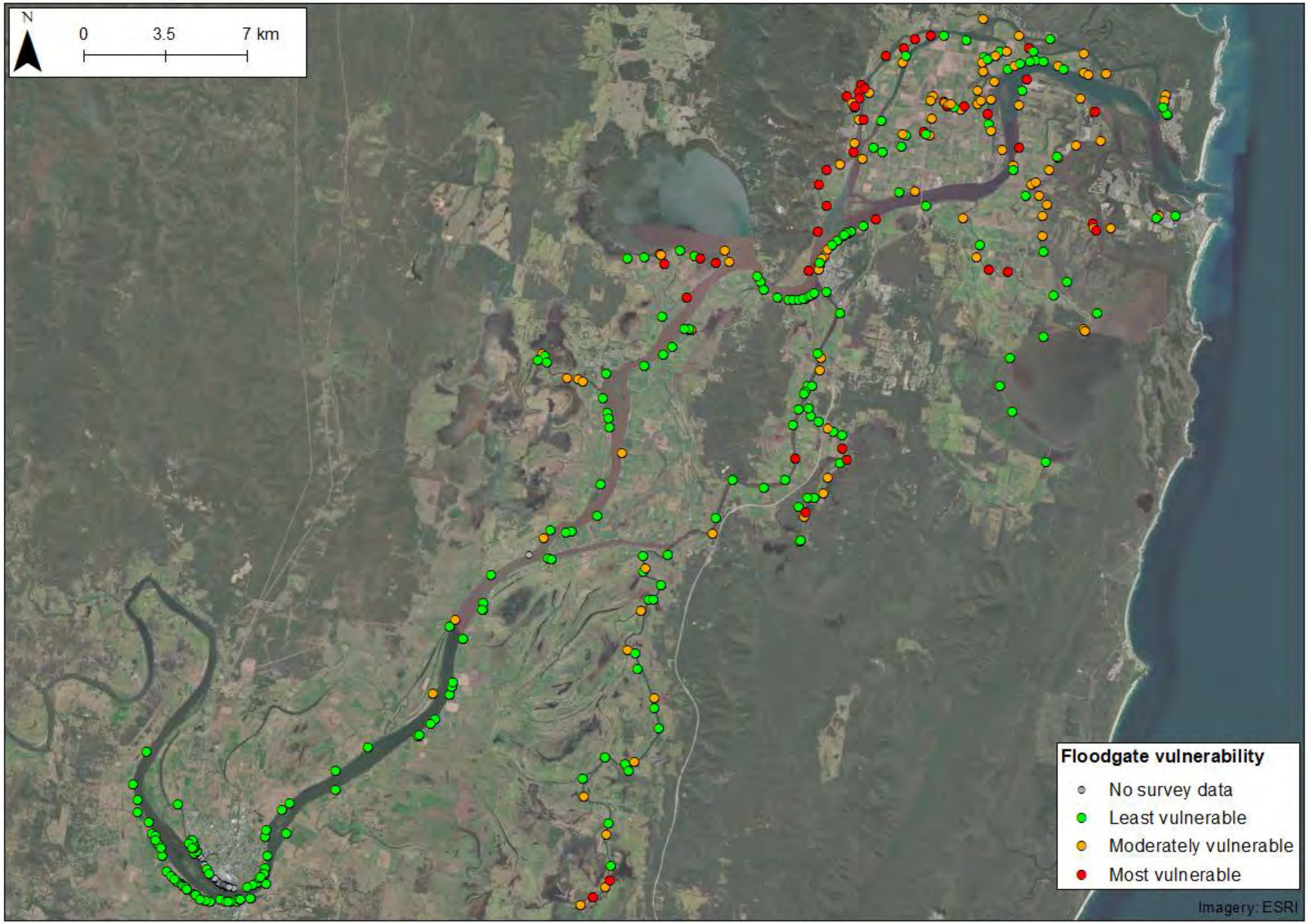

Figure 7-5: Near future (~2050) floodgate vulnerability – Clarence River estuary

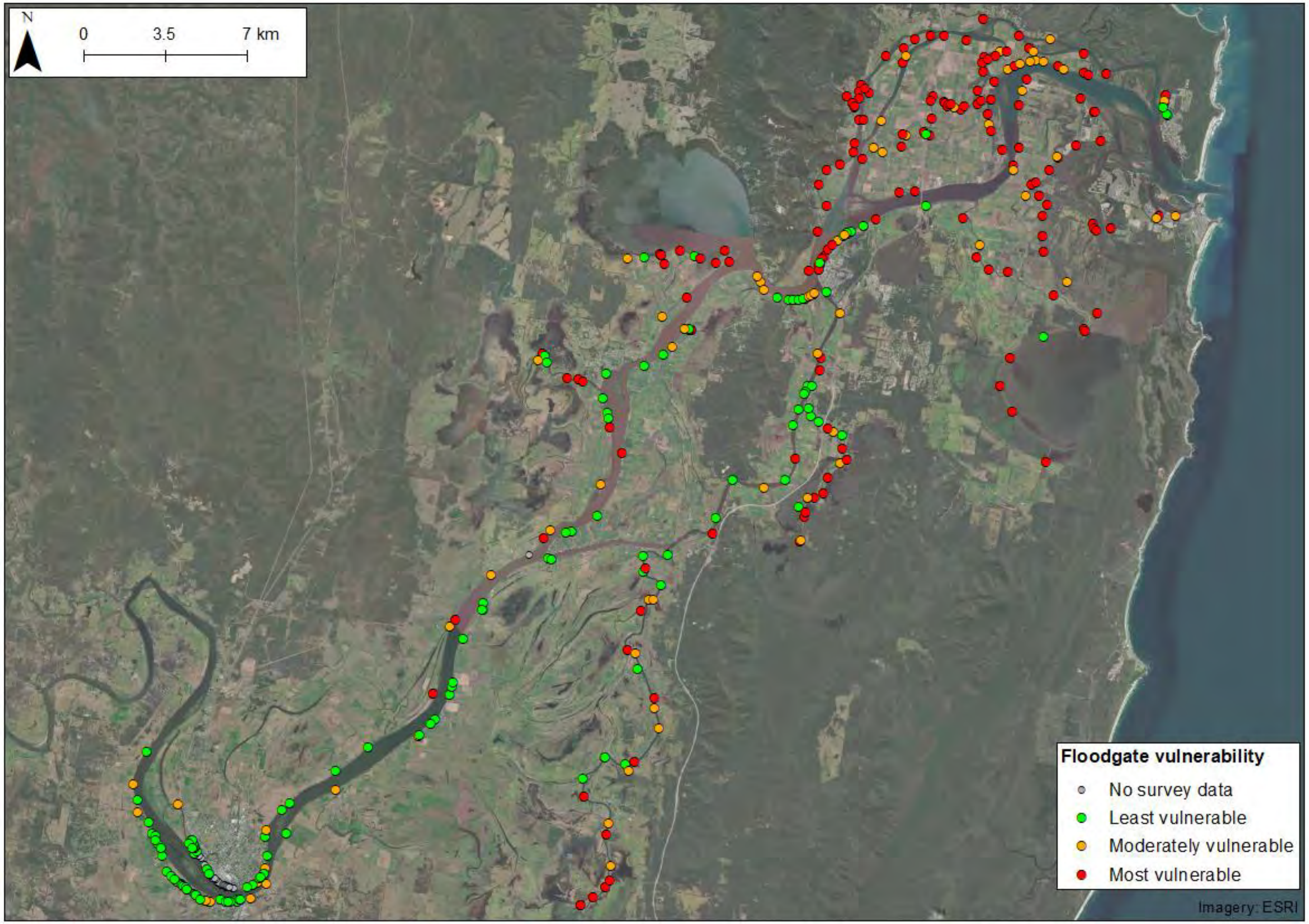

Figure 7-6: Far future (~2100) floodgate vulnerability – Clarence River estuary

7.5 Floodplain vulnerability

Coastal floodplains are vulnerable to sea level rise as they are susceptible to increased inundation times (Glamore et al., 2016b). Inundation can increase for a number of reasons, including increased flooding due to higher ocean levels, tidal inundation due to higher king tides, and reduced drainage due to higher average low tide levels. Impacts of sea level rise to flooding are typically assessed in floodplain flood studies by increasing ocean boundary conditions during periods of high catchment inflows (OEH, 2015). Similarly, tidal inundation assessments consider areas at risk of inundation due to higher future high tides (OEH, 2018) which may directly inundate floodplain areas immediately adjacent to water ways, or overtop infrastructure.

In this study, floodplain vulnerability has been assessed with respect to the potential impacts of reduced drainage only. Elevated tidal levels will result in higher low tide elevations and subsequently reduced drainage. This is particularly relevant to low-lying areas where prolonged periods of inundation following wet weather events are expected. Rather than assessing which areas may be directly inundated (as per a tidal inundation assessment), this assessment identifies areas which may be subject to reduced drainage due to low gradients between the floodplain and estuary water levels. Reduced day-to-day drainage has the potential to significantly impact future floodplain land uses and productivity. The floodplain vulnerability assessment presented here is a first pass assessment that identifies floodplain infrastructure and areas that may be impacted by reduced drainage due to sea level rise in the near to far future.

The floodplain vulnerability assessment methodology, as described in the Section 11 of the Methods report (Rayner et al., 2023), provides an indication of the floodplain areas that are likely to be most impacted by reduced drainage. This analysis translates the predicted water level statistics in the estuary, to the floodplain subcatchment topography. Note, this analysis only considers the risk to floodplain drainage that may arise from catchment inflows and does not consider other modes of floodplain inundation such as movement of estuarine water through underground aquifers to the floodplain. The three (3) key water level statistics described in Section 7.3 have been used in this analysis (5^{th}, 50^{th} and 95^{th} percentile water levels). The floodplain areas above the 95^{th} percentile water levels are not considered to be vulnerable under this assessment. These are outlined in Table 7.4 and Figure 7-7.

Figure 7-8 to Figure 7-11 illustrate the floodplain vulnerability of the Clarence River floodplain for the historic (HS), present day (PD), near future (NF) and far future (FF) sea level rise scenarios. Detailed mapping for each floodplain subcatchment is provided in Section 8. Note that these figures may not be indicative of the actual areas to be inundated due to sea level rise as they do not account for localised impediments to flow (such as levee banks, culverts, floodgates or hydraulic losses) or any localised dampening/amplification of tides that may occur through the smaller drainage channels. The purpose this analysis is to highlight areas at risk of reduced drainage, rather than areas that may be actively inundated by tidal waters due to sea level rise.

The total floodplain areas below the water level percentiles for the HS, PD, NF and FF sea level rise scenarios for the Clarence River are summarised in Table 7-5. While the area below the 5^{th} percentile increases by over five (5) times between present day and the near future, this increases to more than 600 times in the far future to over 8,100 ha.

Table 7.4: Rules for floodplain drainage vulnerability

Classification	Criteria	Description
High risk	Land with an elevation below the 5th percentile water level (approximate low tide level)	Water can only drain from this land effectively 5% of the time, or for around 1 hour in a day. These areas are typically permanently inundated and difficult to drain without additional mechanical assistance (i.e. pumping).
Medium risk	Land with an elevation below the 50th percentile water level (median water level)	Water can drain from this land effectively 50% of the time, or for around 12 hours in a day. These areas are generally difficult to drain efficiently.
Low risk	Land with an elevation below the 95th percentile water level (approximate high tide level)	Water can drain from this land effectively 95% of the time, or for around 23 hours in a day. These areas can be impacted by inefficient drainage, particularly after flood events.
Not vulnerable	Land with an elevation above the 95th percentile water level (approximate high tide level)	Water can drain from this land effectively more than 95% of the time, or for more than 23 hours in a day. These areas are generally not impacted by reduced drainage.

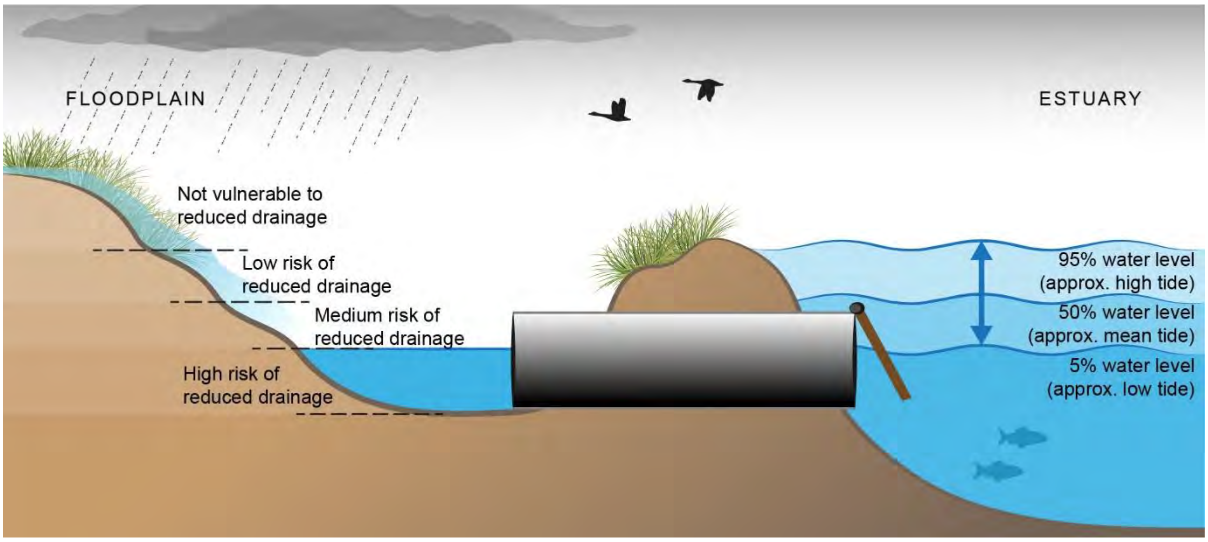

Figure 7-7:Floodplain drainage vulnerability

Table 7-5: Total area (ha) of the Clarence River floodplain vulnerable to reduced drainage

Vulnerability Status	Level criteria	Historic Scenario (HS) ~1960	Present Day (PD) 2020	Near Future (NF) ~2050	Far Future (FF) ~2100
		Area (ha)			
Low	50th percentile water level < Land elevation < 95th percentile water level	8,426	10,461	11,976	19,008
Moderate	5th percentile water level < Land elevation < 50th percentile water level	295	1,132	3,231	8,546
High	Land elevation < 5th percentile water level	3	14	77	8,163

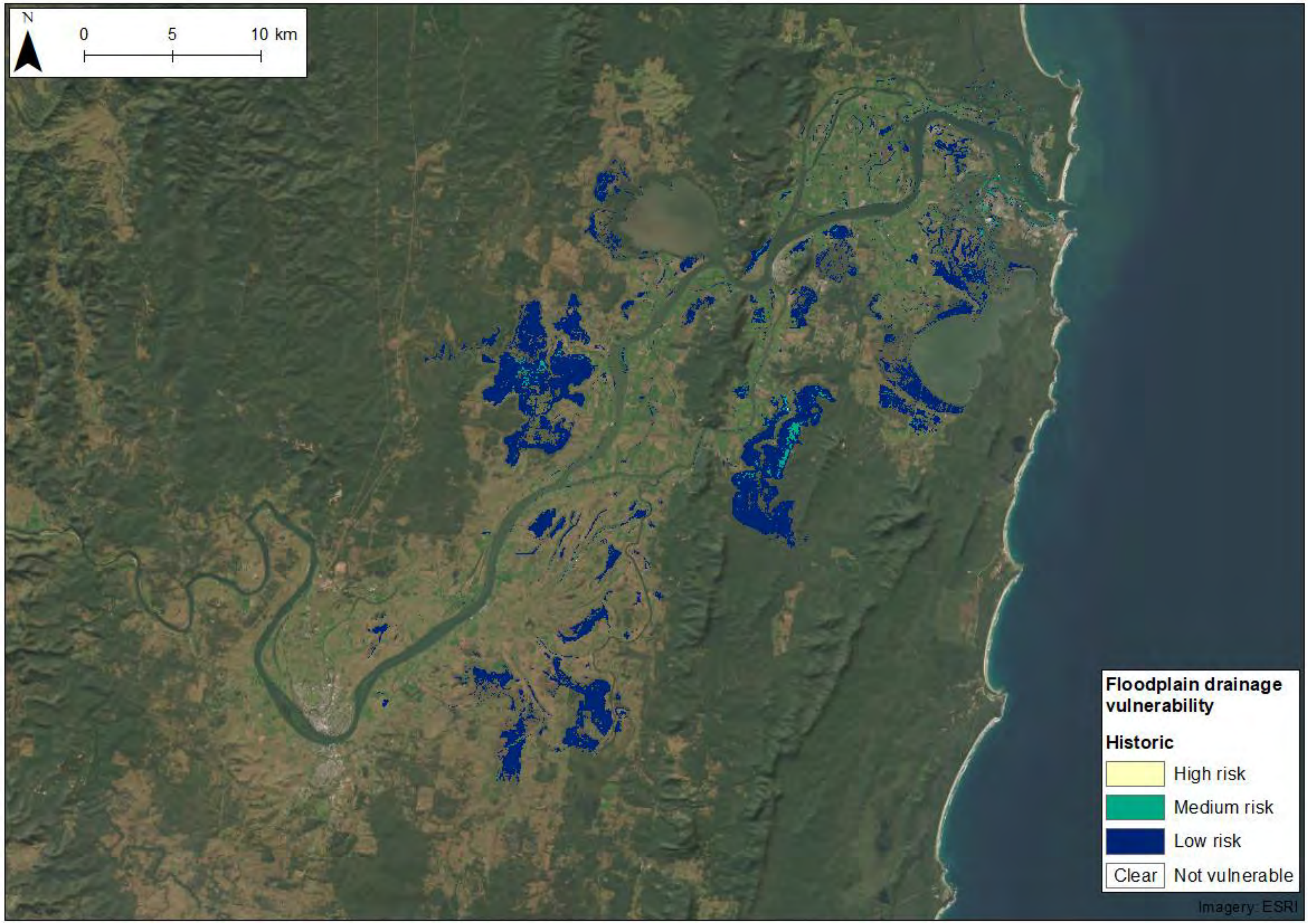

Figure 7-8: Historic (~1960s) floodplain vulnerability – Clarence River estuary

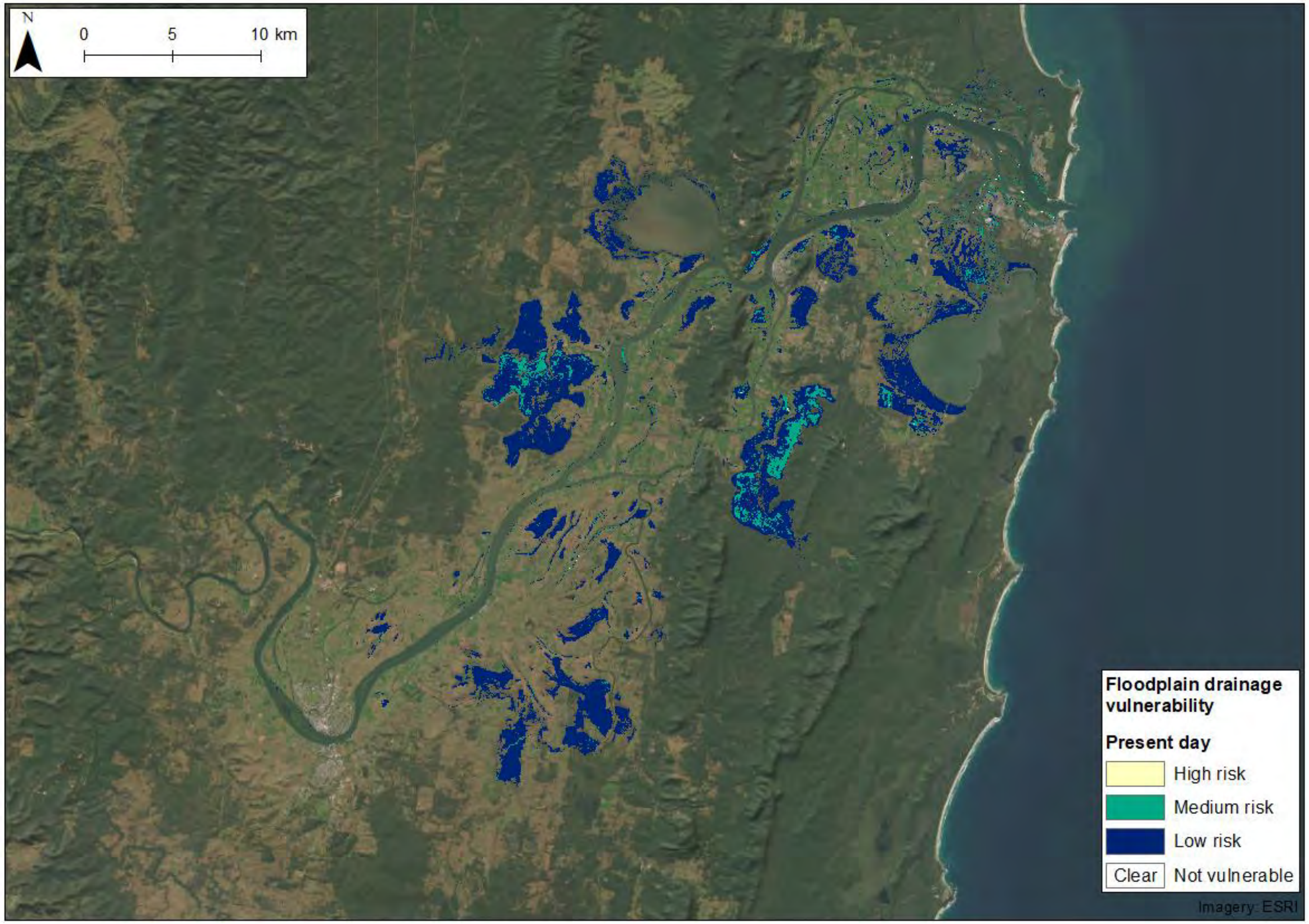

Figure 7-9: Present day floodplain vulnerability – Clarence River estuary

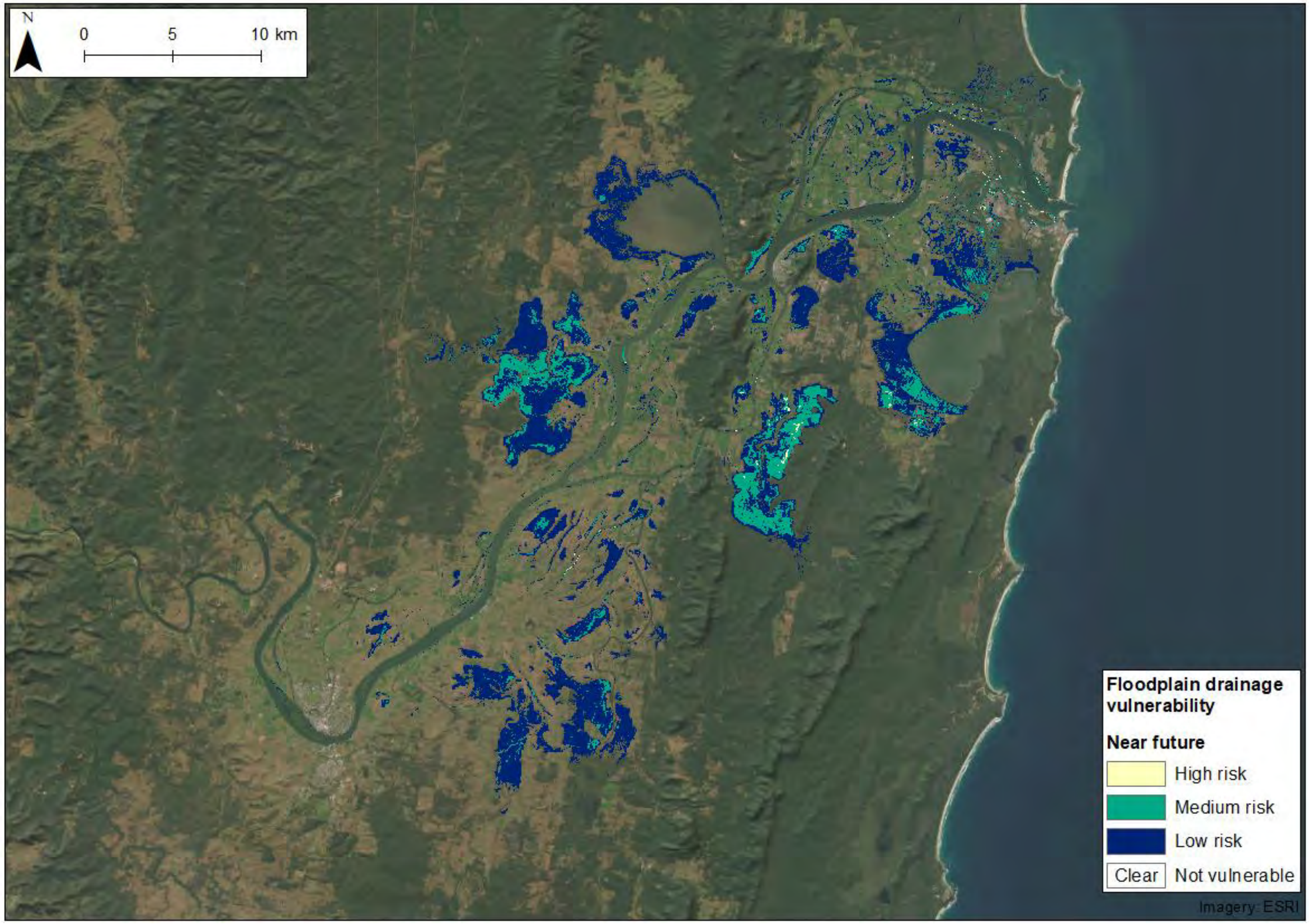

Figure 7-10: Near future (~2050) floodplain vulnerability – Clarence River estuary

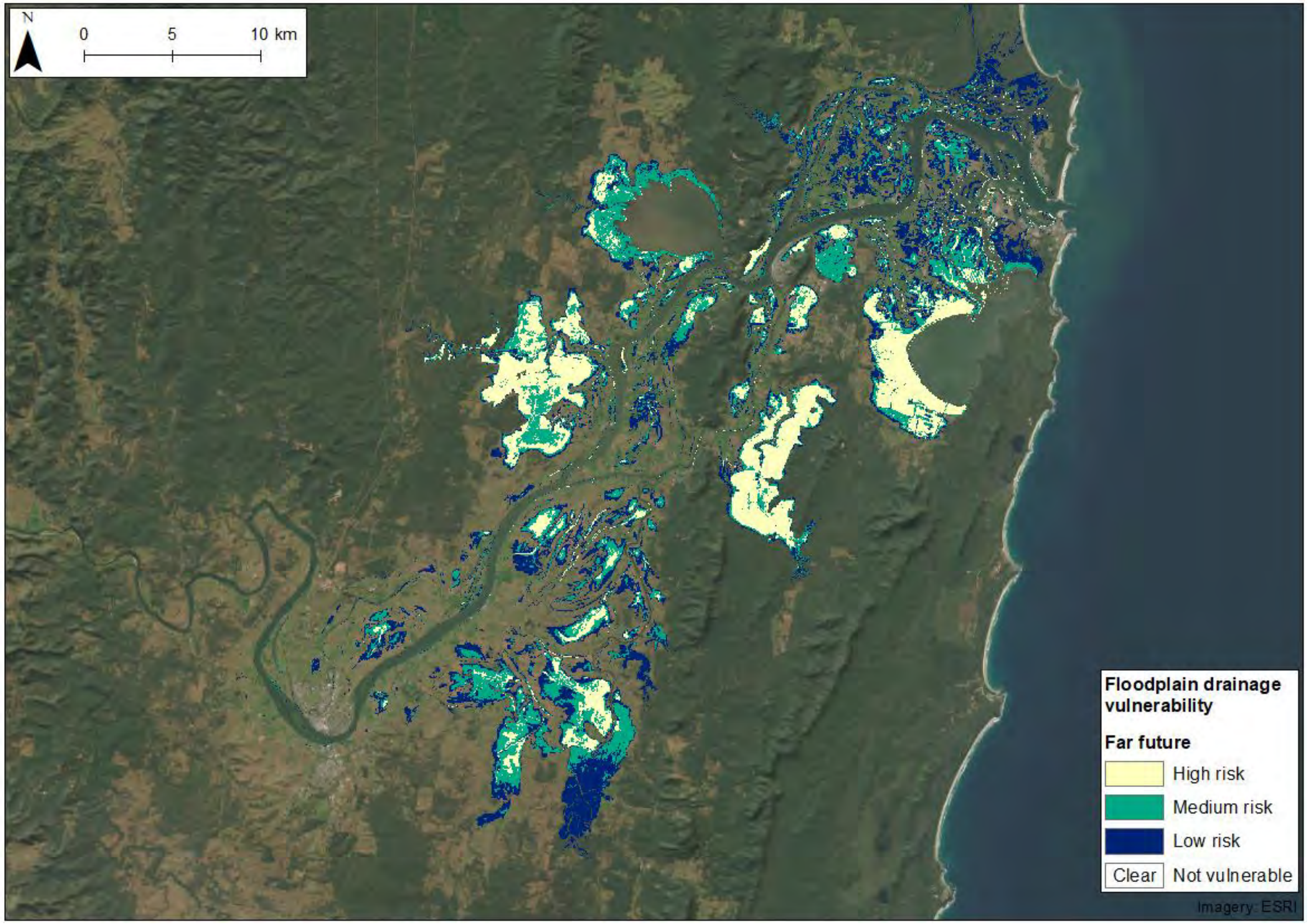

Figure 7-11: Far future (~2100) floodplain vulnerability – Clarence River estuary

8 Subcatchment management options

8.1 Preamble

Management options have been suggested for each subcatchment of the Clarence River floodplain. They include options for short and long-term strategies to reduce the impact of ASS drainage and blackwater generation. Short-term management options are typically implementable within the next one (1) to ten (10) years and assume existing land use practices will continue, while long-term management targets require a longer time period for implementation or a greater upfront investment. Existing remediation has also been considered in the development of future strategies, where it is relevant.

The management options provided in this section are intended as a guide only. Further information and investigation, including incorporation of current on-ground works and management initiatives is required to confirm any on-ground works are applicable, and to determine the required engineering specifications prior to implementing any remedial works. Site investigations should adequately consider the potential impact of any remedial work on existing ecological values, as well as the impact on upstream and adjacent landholders. Any changes in management of these areas will require consultation with local landholders and a comprehensive understanding of, and a plan to mitigate, the social and economic impacts of changes in land management on the community. Additional detailed site investigations required may include - subcatchment hydrological assessments, data collection and monitoring, additional ASS sampling and analysis, and detailed design. Community, landholder, and stakeholder consultation and engagement will also be required.

8.2 Explanation of key information

8.2.1 Summary table

A summary table is provided for each floodplain subcatchment which includes information on priority rankings (for blackwater and acid), drainage and infrastructure, ASS elevations, sea level rise predictions, land uses, proximity to sensitive receivers, and a brief summary of land value and productivity. An example of the summary table provided is shown in Table 8-1, including an explanation of each value.

8.2.2 Floodgates and tenure

The location/number of known end of system floodgates is provided in mapping and the summary tables. In this project, ‘end of system’ is used to refer to any infrastructure that discharges directly into a river, creek or drain that is unrestricted by other infrastructure (i.e. there are no other floodgates located downstream). Infrastructure that is upstream of another floodgate is not included in mapping or the infrastructure counts.

Tenure is provided where known information is available. Information for privately owned infrastructure is difficult to determine as there is no central database. Where the tenure is unknown, it is classified as ‘Private/Unknown’. A summary of all known infrastructure is provided in Appendix F.

Table 8-1: Subcatchment data summary table

Value	Description
Acid priority rank: #	**Final rank in floodplain for acid generation**
Blackwater priority rank: #	**Final rank in floodplain for blackwater generation**
<u>Infrastructure</u>	
Approximate waterway length (km)	Total length of waterways below 5 m AHD
# Privately owned end of system structures	Number of private floodgates (includes floodgates with unknown tenure)
# Publicly owned end of system structures	Number of public floodgates
# End of system structures within coastal wetlands	Total number of floodgates located within Coastal Management SEPP coastal wetlands
# Publicly owned end of system structures within coastal wetlands	Number of public floodgates located within Coastal Management SEPP coastal wetlands
Primary floodplain infrastructure (floodgate ID)	Floodgate ID (or name, where relevant) for significant infrastructure, based on Council records where possible (see Appendix F for more information)
<u>Elevations</u>	
Invert of primary infrastructure (m AHD)	Invert level(s) of significant infrastructure (may be a range)
Average AASS elevation (m AHD)	Approximate elevation of AASS across catchment
Average PASS elevation (m AHD)	Approximate elevation of PASS across catchment
Median blackwater elevation (m AHD)	Median elevation from blackwater prioritisation analysis
Present day low water level (m AHD)	5th percentile water level from present day estuary model
Near future low water level (m AHD)	5th percentile water level from near future estuary model
Far future low water level (m AHD)	5th percentile water level from far future estuary model
<u>Proximity to sensitive receivers</u>	
Oyster leases (km) Saltmarsh (km) Seagrass (km) Mangroves (km) Coastal Management SEPP coastal wetland (km)	Distance (along the river channel) to sensitive receivers from any discharge point (may be within catchment)
<u>Land use</u>	
Total floodplain area (ha)	Total floodplain area below 5 m AHD, excluding tidal waterways
Classified as conservation/minimal use (ha (%)) Classified as grazing (ha (%)) Classified as forestry (ha (%)) Classified as sugar cane (ha (%)) Classified as horticulture (ha (%)) Classified as other cropping (ha (%)) Classified as urban/industrial/services (ha (%)) Classified as marsh/wetland (ha (%)) Other (ha (%))	Area (percentage of floodplain) classified for various land uses below 5 m AHD
<u>Land values</u>	
Estimated total primary production value ($/year):	Total estimated production value of floodplain below 5 m AHD, based on ABS data from the region
Average land value above X m AHD ($/ha) Average land value below X m AHD ($/ha)	Average land value above/below the median blackwater elevation (X m AHD), based on NSW Valuer General data Rural properties only included, below 5 m AHD

8.2.3 Sea level rise vulnerability

Details of the sea level rise vulnerability assessment are provided in Section 7, but are summarised here to assist in the interpretation of the management options. Historic measured tidal records show that mean sea levels off the NSW coast are increasing (e.g. Glamore et al., 2016b; White et al., 2014). Climate scientists project that sea levels will continue to rise and that the rate of rise is likely to accelerate. Increased mean sea levels will have implications for the drainage of all NSW estuaries and floodplains, with reduced drainage efficiency resulting in higher floodplain inundation levels during flood events and increased inundation durations.

Acknowledging the potential impacts of sea level rise on each floodplain subcatchment informs potential remediation strategies. For each subcatchment, mapping of drainage vulnerability is presented for the present day (2020), near future (~2050), and far future (~2100) based on the results of hydrodynamic modelling of estuarine water levels. Water level statistics are based on 24 months of predicted tidal dynamics, and represent both wet and dry years. Mapping includes:

- **Floodgate vulnerability:** a vulnerability status (most, moderately or least vulnerable) of floodgates based on modelled downstream water levels. Vulnerability is based on water level statistics and floodgate geometry and provides an indication of a reduced drainage potential, summarised in Table 8-2. More information on this assessment can be found in Section 7.4;
- **Floodplain vulnerability:** represented as downstream water level statistics (5th, 50th and 95th percentile) translated directly onto upstream floodplain topography. Note that this simplified 'bath tub' approach does not take into account floodgates, hydraulic losses, or dampening/amplification through floodplain drainage channels. The purpose of the floodplain vulnerability analysis is to identify areas likely to be directly impacted by higher estuarine water levels and reduced drainage, rather than areas that may be actively inundated by tidal waters due to sea level rise. The relevance of each of the water level statistics is:
  - **5th percentile water level** (water levels are below this 5% of the time, or around 1 hour a day) – this represents a low tide water level at a given location. Areas below the 5th percentile water level are typically permanently inundated and difficult to drain without additional mechanical assistance (i.e. pumping);
  - **50th percentile water level** (water levels are below this 50% of the time) – this is a median water level. Areas below the 50th percentile water level are generally difficult to drain efficiently; and
  - **95th percentile water level (**water levels are below this 95% of the time, or around 23 hours a day) – this represents a high tide water level at a given location. Areas below the 95th percentile water level can be impacted by inefficient drainage, particularly after flood events.

Table 8-2: Assessment of floodgate vulnerability, based on downstream water levels (see Figure 7-2)

Colour	Classification	Criteria
Green	Least Vulnerable	Obvert > 95th percentile water level
Orange	Moderately Vulnerable	95th percentile water level > Obvert > 50th percentile water level
Red	Most Vulnerable	Obvert < 50th percentile water level

Note: Obvert is the inside top of the floodgate structure.

As part of the sea level rise vulnerability assessment, an infographic (example shown in Figure 8-1) has been provided to summarise the vulnerability of primary floodplain infrastructure. Note that this does not include all floodplain drainage infrastructure. Primary floodplain floodgates include infrastructure that plays a significant role in draining the floodplain catchment (e.g. drains a high order floodplain waterway and/or provides drainage for a significant area of the subcatchment).

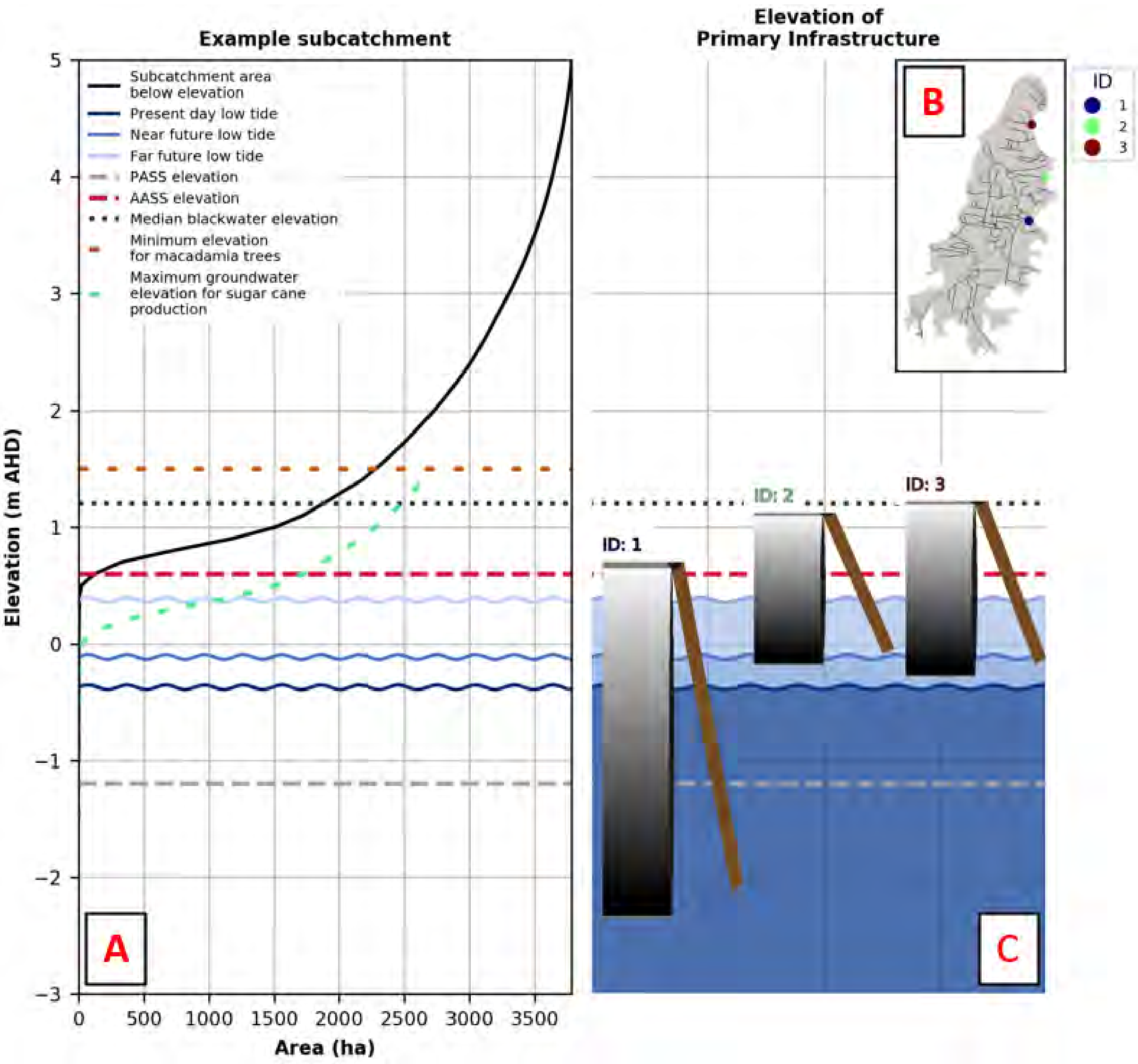

Figure 8-1: Reduced drainage vulnerability summary figure example

These figures are separated into three (3) panels (highlighted as “A”, “B” and “C” in Figure 8-1), which include the following key information:

- **Panel A** summarises key elevations in the subcatchment, including:
    - The area of the subcatchment below 5 m AHD elevation;
    - The present day, near future and far future low tide levels (approximated by the 5th percentile water levels) modelled in the main river channel immediately downstream of the subcatchment;
    - Average subcatchment potential acid sulfate soil (PASS) and actual acid sulfate soils (AASS) elevation;

- The median blackwater elevation within that subcatchment;
- The minimum recommended ground elevation for developing and managing macadamia trees (+1.5 m AHD), based on the recommendation of Bright (2020); and
- The maximum groundwater elevation for sugar cane production (approximately 0.5 m below the ground elevation), based on the findings of Rudd and Chardon (1977). Frequent water logging resulting in higher water tables can reduce sugar cane crop yield.

- **Panel B** shows the location of the primary floodplain floodgates within the subcatchment; and
- **Panel C** which shows the elevation (invert and obvert) of each primary floodgate in the relevant subcatchment, relative to the present day, near future and far future low tide conditions. Each of these are labelled with the floodgate ID. These floodgates are only designed to show elevation of the floodgate, and do not reflect other information such as the number of culverts, the shape of the culvert or the height of the headwall.

This infographic, and the sea level rise vulnerability of infrastructure more generally, focuses on the impact of reduced drainage from increasing low tides. While this provides a good indication of reduced drainage potential, it is acknowledged that high tide levels also impact floodgate functionality. The tidal range (based on the 5th and 95th percentile modelled water levels) in the main river channel downstream of the subcatchment is provided on each figure for reference.

8.2.4 Costs and benefits of changes in land management

Changes to land management and remediation of coastal floodplains can have substantial environmental benefits including improved water quality, however there are also costs associated with capital works and changing land use. The cost of on-ground work , including factors such as compensation for changes in land use, and how to acquire funding are often key limiters to whether environmental remediation is pursued. To provide land managers with an order of magnitude cost estimate associated with the proposed management strategies, a first-pass estimate of costs is provided for:

- Land acquisition – based on NSW Valuer General database;
- Upfront costs – based on unit values for restoration (e.g. drain infilling per km) presented in Section 10 of the Methods report (Rayner et al., 2023) ; and
- Lost productivity – estimated based on the area of land impacted by proposed management option and average productivity for different land uses (present-day) in the catchment.

More information on the cost estimates used in this study is presented in Section 10 of the Methods report (Rayner et al., 2023). The total cost of implementation would also include additional investigation/studies, including (but not limited to) environmental assessments, landholder negotiations, flood studies, possible legal costs, and monitoring programs that may be required prior to implementation. Note, these studies/investigations will need to be considered during the planning phase to inform any changes in management. They will need to consider requirements, such as Coastal Management SEPP coastal wetland mapping, which may trigger certain development pathways and/or additional expenses.

Similarly, understanding the relative benefits of the proposed land management changes is important when prioritising on-ground works. In this report, benefits have been qualitatively scored (e.g. negligible, low, moderate, high) based on the effectiveness of the changed land management in regards to the effectiveness of improving wetland habitat and fish passage and reducing the impacts of ASS and blackwater. This is based on the type of remediation, experience and engineering judgement.

There are also emerging markets that may allow landholders to pursue environmental remediation on private land in an economically viable way, as the value of biodiversity, conservation and carbon sequestration is realised. Examples of such pathways currently include Biodiversity Stewardship Agreements under the NSW Biodiversity Offset Scheme, or the Australian Government Clean Energy Regulator emissions reduction fund. It is anticipated that such pathways may become increasingly common into the future, which may incentivise land use changes in some of the coastal floodplain areas.

However, the benefits of land management changes and/or remediation of wetland areas can include other aspects, including:

- Agricultural benefits – such as reduced weed/drain maintenance costs associated with saline flushing of drains, improved productivity through well designed drainage, better drought resilience or improved water quality. Note that any changes in land management must be completed with the cooperation and consideration of local landholders;
- Reduced vulnerability of land uses to sea level rise – sea level rise may impact the productivity of existing land uses through reduced drainage and changes in salinity. Some proposed land management strategies may be better suited to adapt to changing environmental stressors; and
- Reduced maintenance costs - it is important to recognise continuing with current floodplain management is not without cost. Floodplain infrastructure throughout estuaries requires significant capital expenditure to maintain and replace damaged infrastructure or infrastructure that has come to the end of its functional life. Some changes to land management may reduce the need for on-going maintenance expenditure (e.g. floodgate removal).

While the dollar value of benefits has not been provided for the recommended management options, a number of studies on remediation of ASS affected areas in NSW have shown that the benefits of remediation outweighed the costs. These include:

- A cost-benefit analysis of a large scale restoration of the Big Swamp floodplain on the Manning River was conservatively estimated to have a benefit to cost ratio of 7:1 (Harrison et al., 2019), despite not including the costs of acid discharges in the assessment;
- A cost-benefit analysis of modifications of the Bagotville Barrage to allow tidal flushing and implement works to reduce acid drainage from Tuckean Swamp showed the benefit-cost ratio would range from 1.1:1 to 5.7:1 (Read Sturgess and Associates, 1996) considering improvements to fishing only (variations considered a pessimistic scenario with higher than expected costs and lower than expected benefits, and an optimistic scenario with lower than expected costs and higher than expected benefit for improved fishing opportunities); and
- A cost-benefit analysis of remediating ASS affected areas on the Maria River floodplain was estimated to have a benefit-cost ratio of 1.1:1 to 3:1 (Aaso, 2000) (using a pessimistic and optimistic scenario), before considering any non-market ecosystem service benefits from remediation works.

More details on the benefits of changes in land management are provided in Section 10 of the Methods report (Rayner et al., 2023).

8.2.5 Waterway classification

Connected natural creeks and waterways provided important aquatic habitats prior to human intervention. Waterways below a 5 m AHD elevation have been categorised as part of this project into one of four categories to describe if a waterway is natural or artificial. Descriptions for each of the four categories (natural waterbody watercourse, artificial waterbody, watercourse and connector watercourse) are outlined in Appendix A. Details on how waterways have been categorised are provided in Chapter 12 of the Methods report (Rayner et al., 2023).

Waterway categorisations of all identified drainage lines are provided within the management options for each subcatchment. Where possible, management options focus on improving aquatic habitat in natural waterways (i.e. natural waterbody watercourses, watercourses or connector watercourses) which would have historically been connected. Drain modifications (e.g. infilling or reshaping) are typically only recommended in artificial waterbodies (or connector watercourses, if appropriate).

8.2.6 Subcatchment management areas

Subcatchments that are identified to have significantly higher ASS or blackwater factors have been further delineated into separate management areas based on geology and drainage. Where there is sufficient data, the ASS prioritisation methodology is repeated within a subcatchment to identify high priority management areas and indicate the potential sources of acid drainage within a subcatchment. Similarly, the median blackwater elevation is superimposed to the management areas to indicate areas associated with high blackwater risk. The reanalysis of management areas is provided in the management options in the Clarence River floodplain for:

- Sportsmans Creek subcatchment;
- Swan Creek subcatchment;
- Gulmarrad/East Woodford Island subcatchment;
- Taloumbi/Palmers Channel subcatchment; and
- Coldstream River subcatchment.

8.3 Sportsmans Creek subcatchment

Acid priority rank:	**1**
Blackwater priority rank:	**2**
<u>Infrastructure</u>	
Approximate waterway length (km)	120
# Privately owned end of system structures	6
# Publicly owned end of system structures	7
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID)	Sportsman Creek Weir, F-1790-FB-0001, F-1805-FB-0001, F-1810-FB, F-2440-FB-0001
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	-1.2 to -0.6
Approximate AASS elevation (m AHD)	0.1
Approximate PASS elevation (m AHD)	-1.0
Median blackwater elevation (m AHD)	1.9
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0.0
Far future low level (m AHD)	0.5
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	34.3
Saltmarsh (km)	7.3
Seagrass (km)	25.5
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	5,739
Classified as conservation and minimal use (ha (%))	2,137 (37%)
Classified as grazing (ha (%))	1,504 (26%)
Classified as forestry (ha (%))	117 (2%)
Classified as sugar cane (ha (%))	208 (4%)
Classified as horticulture (ha (%))	8 (0%)
Classified as other cropping (ha (%))	339 (6%)
Classified as urban/industrial/services (ha (%))	65 (1%)
Classified as marsh/wetland (ha (%))	1,041 (18%)
Other (ha (%))	319 (6%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$1,800,000
Average land value above 1.9 m AHD ($/ha)	$3,700
Average land value below 1.9 m AHD ($/ha)	$3,100

8.3.1 Site description

The Sportsmans Creek subcatchment is located on the north-western side of the Clarence River near Lawrence and the western half of the subcatchment is owned and managed by NPWS, shown in Figure 8-2. As shown in Figure 8-3, the subcatchment is predominantly a low-lying backswamp with a substantial area below 1 m AHD.

The Sportsmans Creek subcatchment includes Everlasting Swamp, an infilled back lagoon system. The name 'Everlasting Swamp' is often used to refer to the whole drainage basin, however it also includes a number of intermittent wetlands (Tulau, 1999a). While the area has been heavily modified with artificial drainage, natural drainage occurs via Sportsmans Creek and smaller tributary systems, including Woody and Reedy Creeks.

Sportsmans Creek Weir, constructed in 1927 by the Sportsmans Creek Drainage Union, remains the dominant feature controlling hydrology within the Everlasting Swamp. The weir consists of 40 floodgates (1.8 m by 1.2 m high) with an invert of approximately -0.6 m AHD and a crest elevation of 0.6 m AHD (Smith, 1999). In the 1960's, drains were constructed through the levees of Sportsmans, Woody and Reedy Creek to improve drainage of low-lying areas upstream of the Sportsmans Creek weir. In the 1980's, a series of levees drainage works were constructed within the subcatchment to assist with flood mitigation and allow agricultural land uses (Tulau, 1999a).

The Little Broadwater, which lies to the north east of Sportsmans Creek weir, once part of the Everlasting Swamp System connected by Sportsmans Creek, was isolated after the construction of a 200 m levee sometime between 1911 and 1927, and construction of the Sportsmans Creek weir in 1927. Previously, Little Broadwater operated as a complex wetland system with areas of brackish, tidal and fresh water (NRCMA, 2006). While the original hydrology of the area would have allowed retention of flood waters for dozens of days, the typical retention time was reduced to around five (5) days with the implementation of the drainage infrastructure (NRCMA, 2006).

The Sportsmans Creek subcatchment was identified as an ASS hotspot by Tulau (1999a). It has been the subject of numerous studies which investigated management of ASS, including Beveridge (1998); Glamore et al. (2019); Smith (1999); Wilkinson (2003) and has undergone significant changes in management and ownership. Low dissolved oxygen (blackwater) has also been identified as an issue in this subcatchment (Glamore et al., 2019; Wilkinson, 2003) and Everlasting Swamp was recognised as a key source of blackwater in the Clarence River floodplain by Walsh et al. (2004). Monitoring of water quality downstream of Sportsmans Creek Weir in 2001 showed a minimum dissolved oxygen (DO) level of 0.1 mg/L, the 25th percentile dissolved oxygen was 3.4 mg/L and median dissolved oxygen level was 4.9 mg/L (MHL, 2001). ANZECC and ARMCANZ (2000) suggests that dissolved oxygen should remain above 5 mg/L for the protection of aquaculture species. At least six (6) fish kill events have been attributed to discharges from the Sportsmans Creek subcatchment (NSW DPI, 2020).

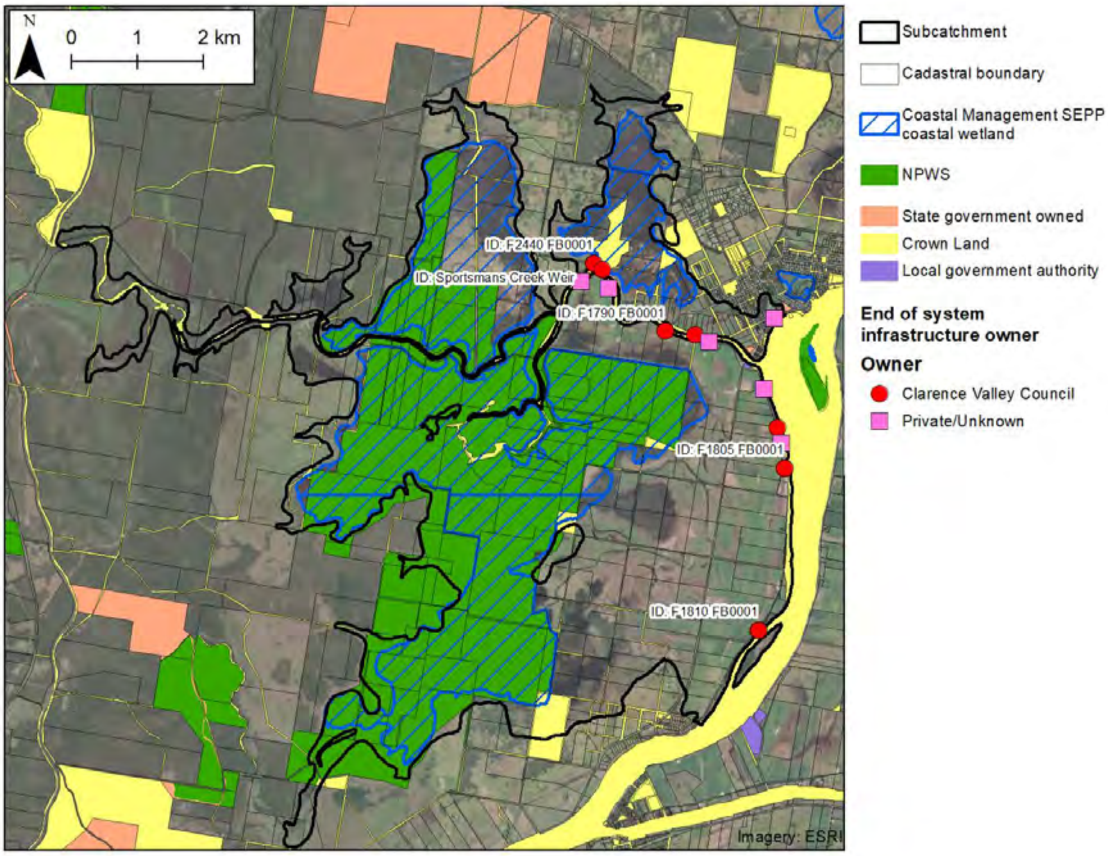

Figure 8-2: Sportsmans Creek subcatchment land and end of system infrastructure tenure

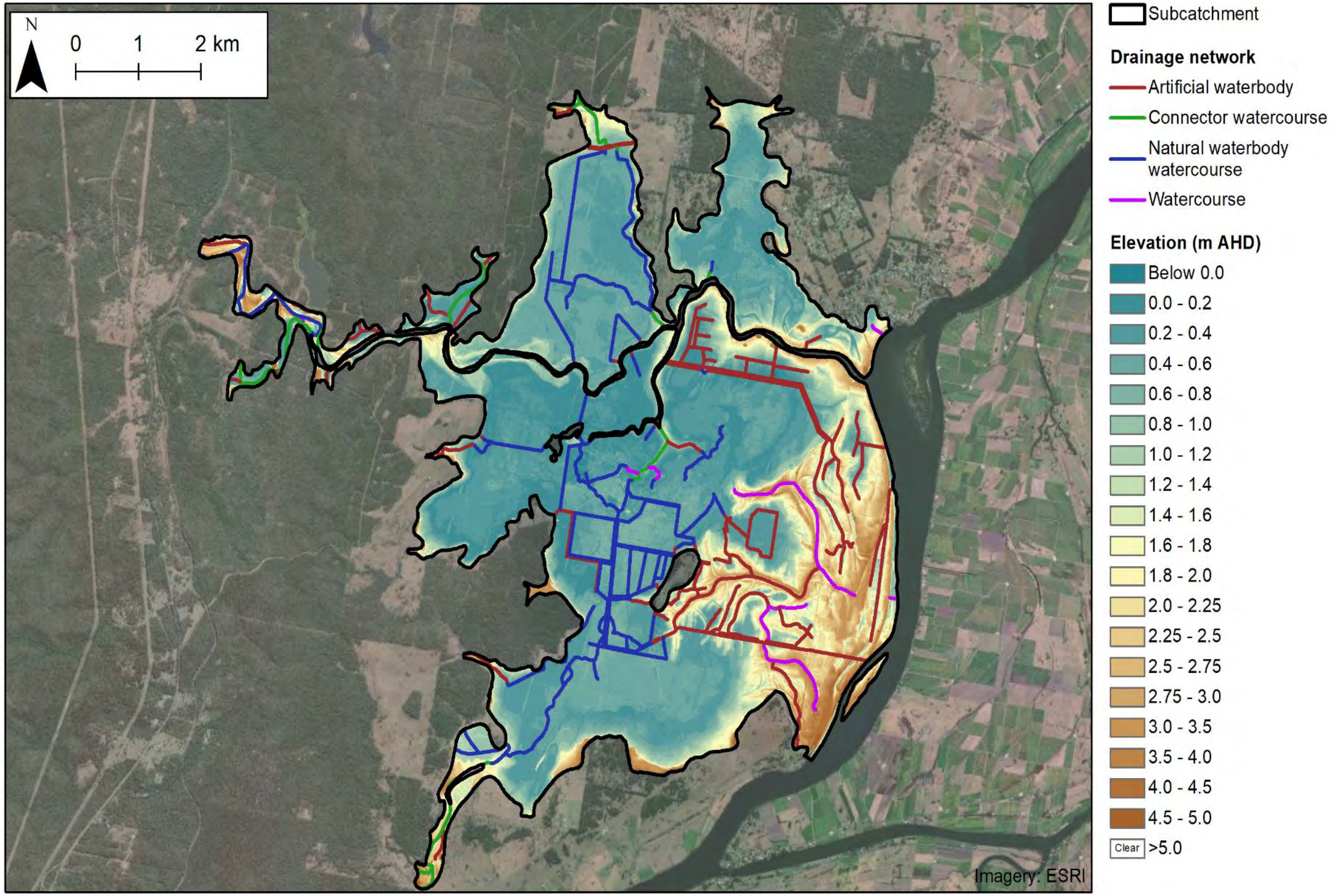

Figure 8-3: Sportsmans Creek subcatchment elevation and drainage network

8.3.2 History of remediation

The Sportsmans Creek subcatchment has undergone significant remediation since it was identified as an ASS hotspot in 1999 (Tulau, 1999a; Tulau, 1999b). Figure 8-4 summarises some of the remediation works that have occurred in the subcatchment including a substantial portion of the subcatchment being purchased by NPWS and a number of floodgate modifications.

In 2007, a portion of Everlasting Swamp (462 hectares) was acquired by Northern Region National Parks and Wildlife Service (NPWS) and managed as a State Conservation Area. However, as the purchased area was located between privately held agricultural land parcels, this limited the scope of remediation works possible at the time.

In 2014, an additional 1,769 hectares was acquired by NPWS (Glamore et al., 2019). This additional land located both north and south of Sportsmans Creek consolidated a significant area for wetland remediation by removing several private holdings and significantly reducing the overall management risk of changing onsite hydrological conditions. In 2016, the NPWS released a Statement of Management Intent for the Everlasting Swamp National Park and State Conservation Area that outlined the values, issues, management directions and priorities for the site. The return of natural flow regimes back into the swamp to improve the ecosystem functions and overall health of the surrounding environment was recognised as the primary long-term management objective for NPWS. However, any changes to the current hydrology depends on the agreement of stakeholders, including adjacent landholders and Clarence Valley Council. The NPWS manage over 80% of the Everlasting Swamp wetland complex. The Everlasting Swamp National Park is mostly surrounded by private landholdings, including some privately owned areas that are mapped as SEPP (Coastal Management) Coastal Wetlands (Glamore et al., 2019).

In 2019, WRL completed an extensive investigation into the hydrodynamics and floodplain processes of Everlasting Swamp, including data gathering, community feedback discussions and modelling of a range of management options (Glamore et al., 2019). These options are in the process of being incorporated into a new management plan for the Everlasting Swamp wetland complex.

In March 2020, NPWS also acquired an additional 176.5 ha south of the previous acquisitions. Although this land has not yet been gazetted as national park, it was purchased with the intent to be added into the existing Everlasting Swamp National Park.

A number of floodgates have been modified in the Sportsmans Creek subcatchment through the Clarence Floodplain Project, run by Clarence Valley Council. Modified structures are shown in Figure 8-4 and include:

- Auto-tidal buoyancy gates on four (4) floodgates, including:
    - Floodgate ID F-2440-FT-0001 at the at the Lawrence/Whalan's flood mitigation drain (built in the 1960s) in the Little Broadwater. The modifications included the construction of two new tidal floodgates with an upstream concrete weir, equipped with drop-boards and fish flaps. The remediation was funded by NSW Fisheries Floodgate program. Water quality monitoring between 2002 and 2007 showed an improvement of discharge water quality in terms of acidity following the restoration of tidal exchange in June 2003 (Northern Rivers Catchment Management Authority, 2006);

- o Floodgate ID F-1810-FT-0001 on Blanches Drain in the south-east corner of the subcatchment. This floodgate is also fitted with a winch. Controlled opening of this floodgate showed improvements in water quality (Johnston et al., 2005a);
  - o Floodgate ID F-1835-FT-0001 and Floodgate ID F-1845-FT-0001 on Woody Creek and Reedy Creek, upstream of the Sportsmans Creek Weir;
- Floodgates fitted with lifting devices (winches or similar) on ten (10) of the floodgates in the Sportsmans Creek subcatchment; and
- Water retention structures (drop board weirs or similar) in at least five (5) locations, including major drains into Imesons Swamp and Harrisons Creek Weir, as shown in Figure 8-4.

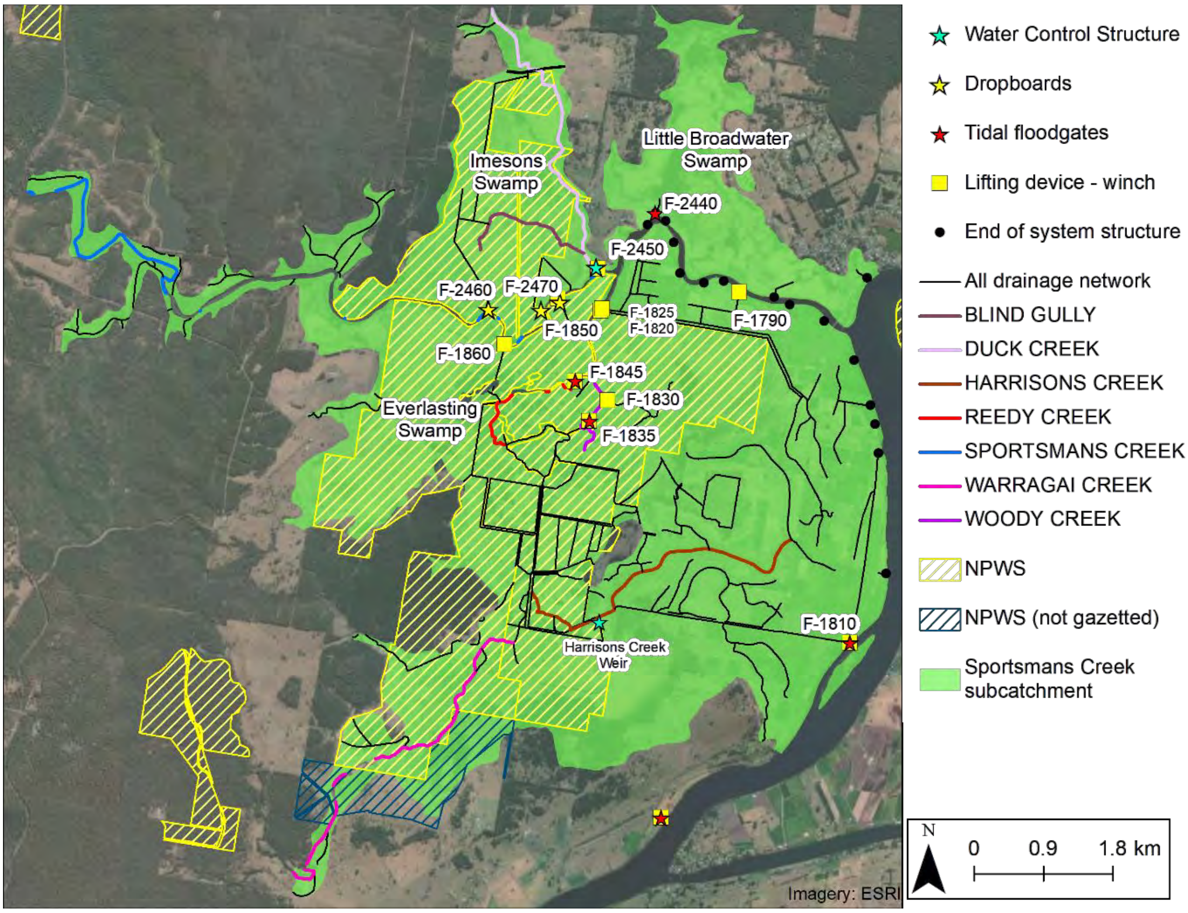

Figure 8-4: Sportsmans Creek subcatchment including previous remediation actions

8.3.3 Prioritisation of management areas in Sportsmans Creek subcatchment

Sportsmans Creek is the highest ranked subcatchment in the Clarence River floodplain with regards to acid generation, and ranked second for blackwater generation potential. The subcatchment has been further divided into four (4) management areas (referred to as SPC1 to SPC4) to provide additional information on the sources of acid and blackwater in the Sportsmans Creek subcatchment. The areas have been delineated based on data availability, elevation, changes in soil acidity, and drainage units.

The management areas have been prioritised for acid generation using the method described in Section 4.2. The results of the acid prioritisation are shown in Figure 8-5 and summarised in Table 8-3.

The highest priority management area was identified as SPC4 in Imesons Swamp, followed by management area SPC1, in the centre of Everlasting Swamp. The Little Broadwater Swamp (management area SPC3) was the lowest priority, primarily due to the lower drainage density and a smaller catchment area.

Figure 8-6 shows the management areas at Sportsmans Creek subcatchment below the median elevation for blackwater generation (+1.9 m AHD). As elevation is a primary driver of the production of blackwater, the areas below this level typically have the greatest contribution to the risk of large scale deoxygenation. All the management areas in the Sportsmans Creek subcatchment contribute to blackwater drainage.

Based on the prioritisation of management areas for acid generation, and the areas below the median elevation for blackwater generation, it is recommended that changing land management to improve water quality should initially focus on management areas SPC4, SPC1 and SPC2.

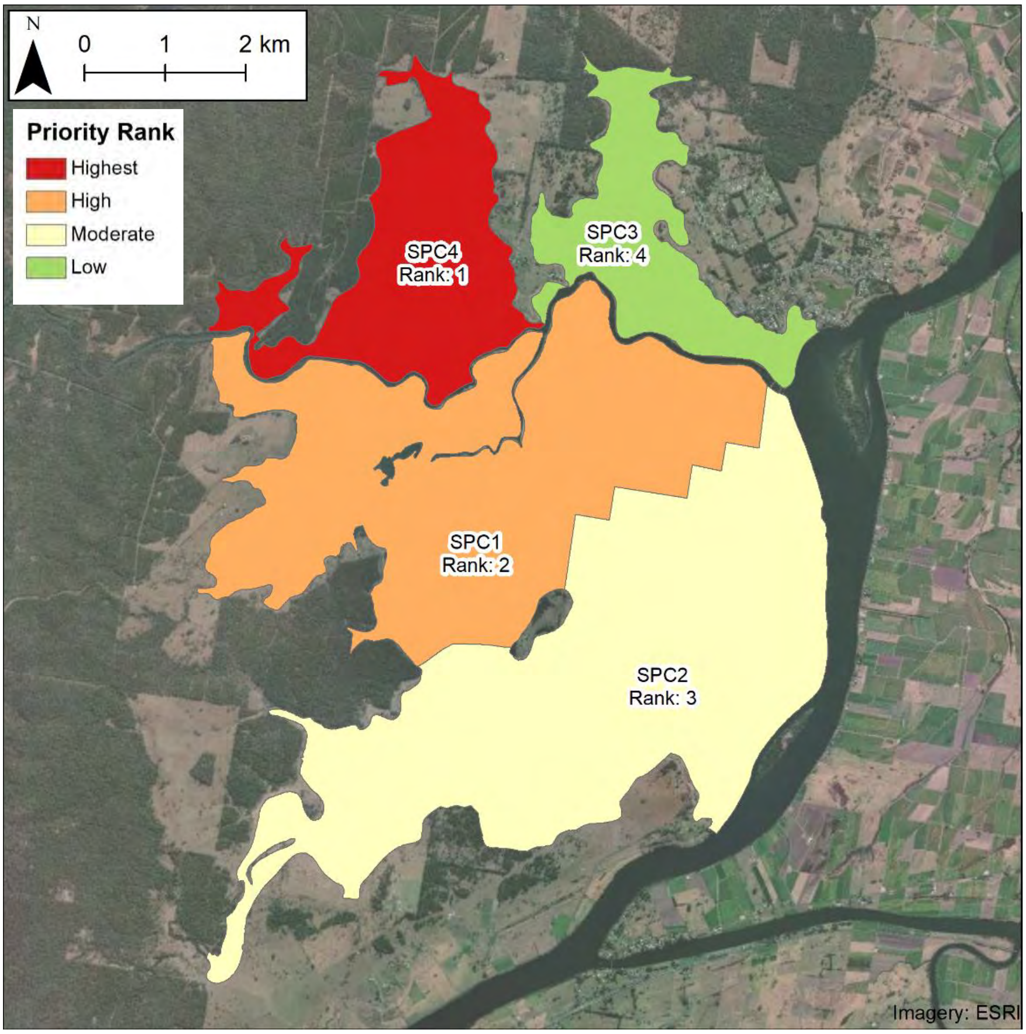

Figure 8-5: Sportsmans Creek subcatchment management areas acid prioritisation

Table 8-3: Management area acid prioritisation of Sportsmans Creek subcatchment

Management area	Groundwater factor	Surface water factor	Final acid factor	Final rank
SPC4	64	1,776	114,241	1
SPC1	25	1,579	39,303	2
SPC2	62	366	22,846	3
SPC3	29	5	158	4

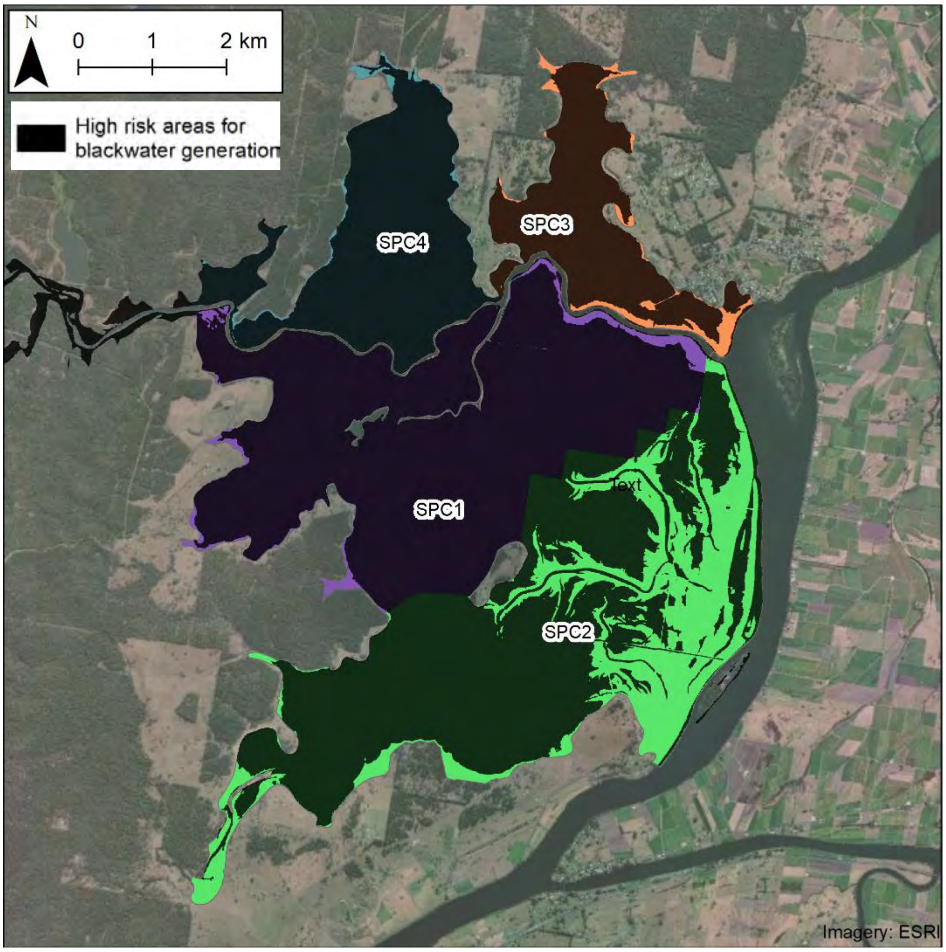

Figure 8-6: High risk areas for blackwater generation in management areas in Sportsmans Creek subcatchment (median blackwater level +1.9 m AHD)

8.3.4 Floodplain drainage - sea level rise vulnerability

Figure 8-7 summarises the vulnerability of the Sportsmans Creek subcatchment to sea level rise. Due to the low topography, the majority of the subcatchment is already classified as low risk. However, in the near future much of this area will be classified as medium risk, although the majority of the low area is already owned by NPWS. Significantly, in the far future, the majority of the subcatchment is classified as high risk and surface water drainage will be significantly impacted throughout the vast majority of the subcatchment.

In the far future, Sportsmans Creek Weir has been identified as ‘Moderately vulnerable’ to sea level rise, while five (5) floodgates will be classified as ‘Most vulnerable’, including three (3) primary floodgates. The remaining two (2) primary floodgates will be classified as ‘Moderately vulnerable’ and six (6) other floodgates remain ‘Least vulnerable’. Increased future estuarine water levels will likely impact drainage of the Sportsmans Creek subcatchment in the near to far future.

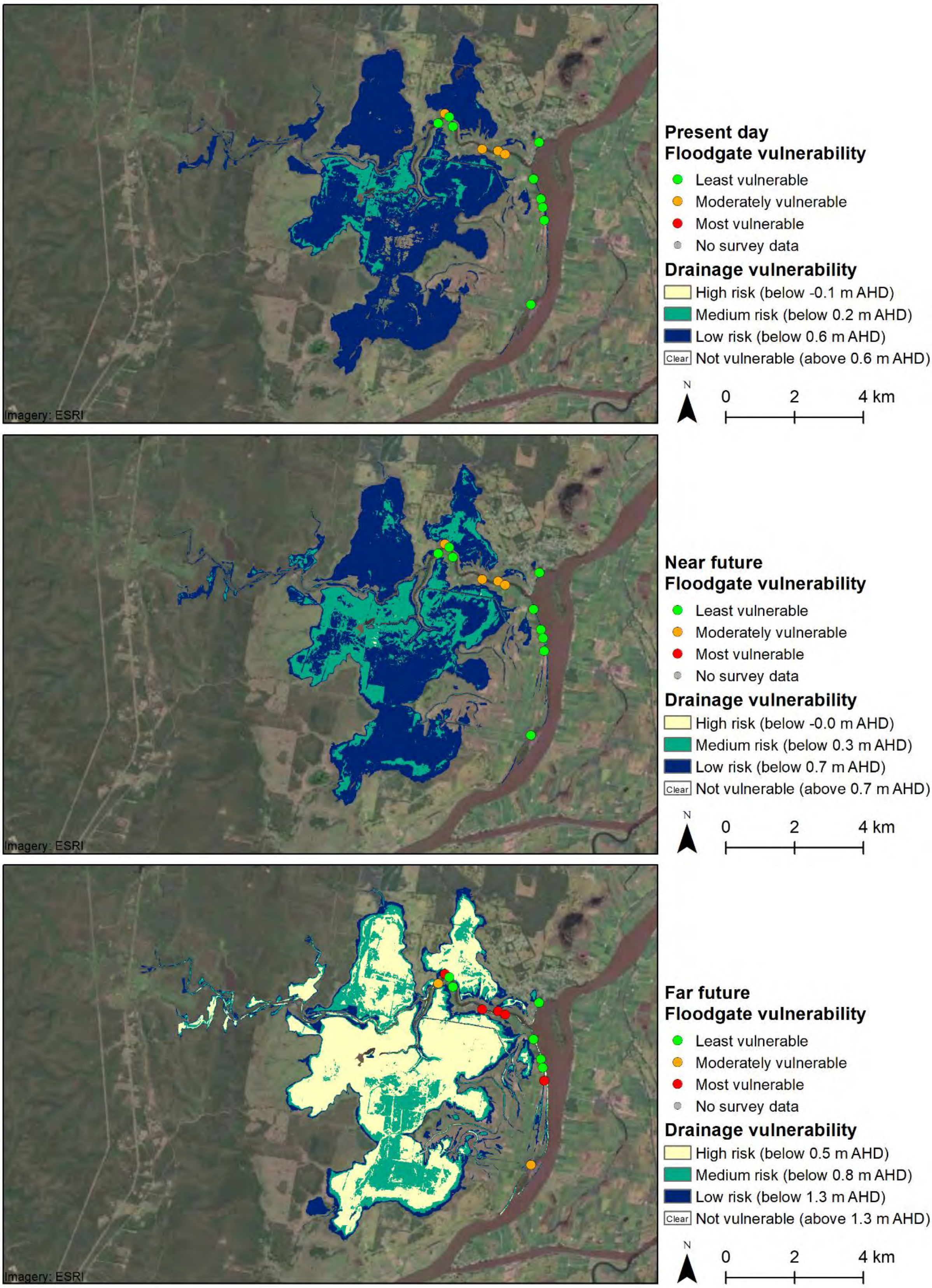

Figure 8-7: Sea level rise drainage vulnerability – Sportsmans Creek subcatchment

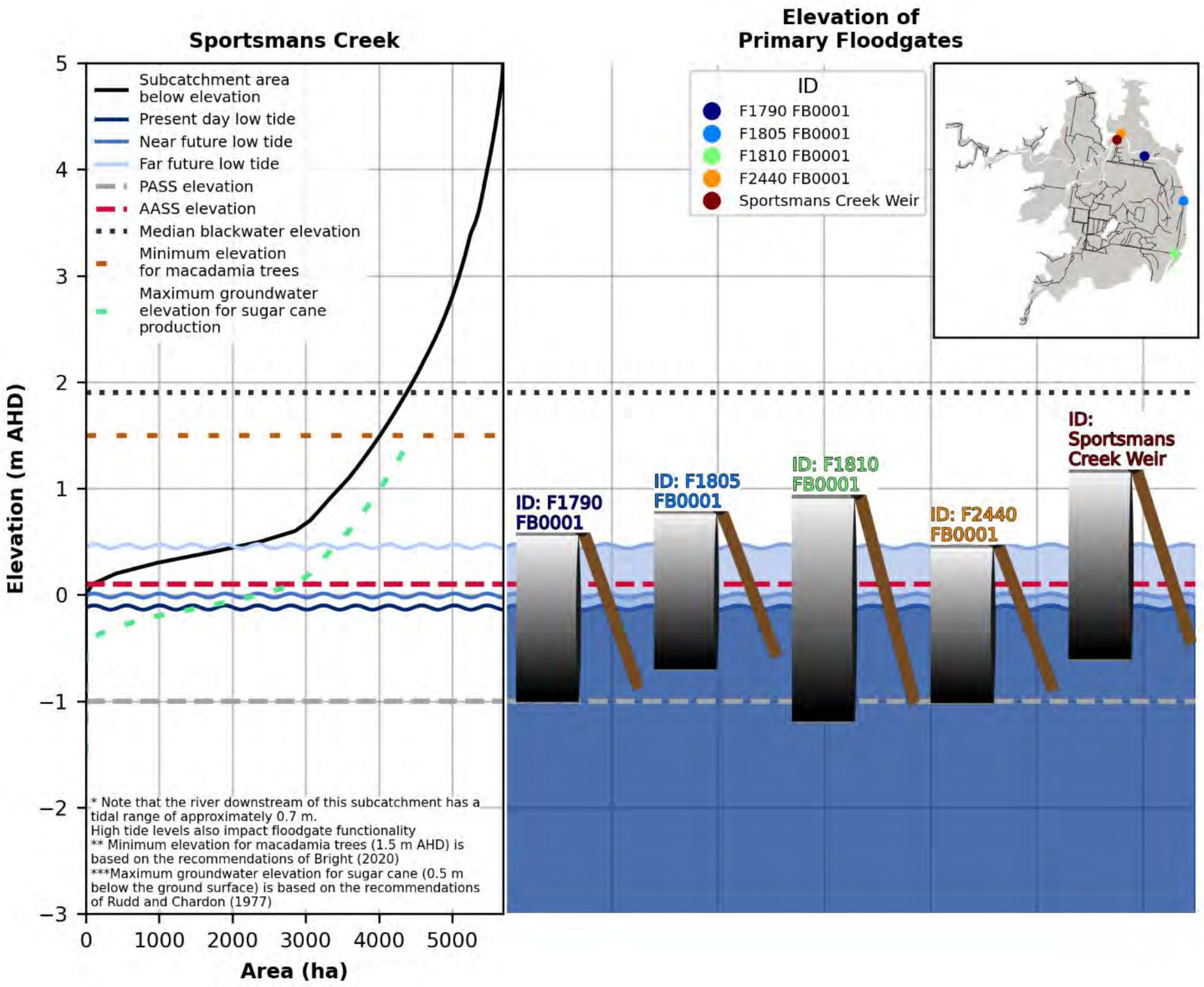

Figure 8-8: Primary floodgates and key floodplain elevations – Sportsmans Creek subcatchment

8.3.5 Management options

Short-term management options

Glamore et al. (2019) completed extensive hydrodynamic numerical modelling of the Sportsmans Creek subcatchment, including investigation of management options to address the impacts of ASS drainage. Improving flushing through this subcatchment may be an effective way to manage dry weather water quality in Sportsmans Creek. Improving or optimising tidal flushing could be considered on all the major floodgates within the system, including the Little Broadwater and Blanches Drain. Other existing infrastructure, such as dropboard weirs, should also be reviewed to ensure they are being managed effectively to limit acidic discharges. Any changes to tidal flushing will have to consider the potential for tidal inundation on adjacent privately owned land, and would require consultation and cooperation from local landholders.

Long-term management options

As discussed in Section 8.3.4, the majority of the Sportsmans Creek subcatchment will be affected by reduced drainage in the near to far future. While the majority of the lowest-lying areas are owned by NPWS, large scale restoration of natural estuarine and freshwater hydrology would be required to have a significant impact on water quality. This may include:

- Removal of artificial levees and flow impediments, possibly including floodgates;
- Redesign of the existing drainage system, infilling most artificial drains or reshaping drains above the PASS layer to maintain surface drainage from upstream areas and encourage tidal flushing; and
- Continue monitoring and maintenance of the National Park and wetland areas.

This strategy would greatly reduce the risk of acid drainage and blackwater runoff from the Sportsmans Creek subcatchment, as well as improve fish and terrestrial habitat in the Clarence River region. This option would cover all management areas, although the higher elevation areas in the east of SPC2 may remain productive for agricultural land uses. Any changes in management, including changes within the boundary of the National Park, will have to consider impacts to adjacent landholders.

Table 8-4: Summary of management options for Sportsmans Creek

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Actively manage floodgates	Moderate	Limited	Negligible
Long-term	Restoration of natural estuarine hydrology	High	High	High

8.4 Swan Creek subcatchment

Acid priority rank:	**2**
Blackwater priority rank:	**3**
Infrastructure	
Approximate waterway length (km)	88
# Privately owned end of system structures	2
# Publicly owned end of system structures	3
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	F-1160-FB, F-1410-FB
Elevations	
Invert of primary floodplain infrastructure (m AHD):	-1.1
Approximate AASS elevation (m AHD)	-0.2
Approximate PASS elevation (m AHD)	-0.9
Median blackwater elevation (m AHD)	1.9
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	0.0
Far future low level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	52.3
Saltmarsh (km)	25.3
Seagrass (km)	43.5
Mangroves (km)	8.9
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	4,752
Classified as conservation and minimal use (ha (%))	5 (0%)
Classified as grazing (ha (%))	3,639 (77%)
Classified as forestry (ha (%))	2 (0%)
Classified as sugar cane (ha (%))	30 (1%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	12 (0%)
Classified as urban/industrial/services (ha (%))	91 (2%)
Classified as marsh/wetland (ha (%))	747 (16%)
Other (ha (%))	226 (5%)
Land values	
Estimated total primary production value ($/year)	$900,000
Average land value above 1.9 m AHD ($/ha)	$7,300
Average land value below 1.9 m AHD ($/ha)	$2,500

8.4.1 Site description

The Swan Creek subcatchment is in the upper Clarence River floodplain and is mostly used for grazing. The subcatchment is almost entirely privately owned, except for a few larger waterbodies and watercourses that are under Crown Land tenure, shown in Figure 8-9.

A large levee separates the subcatchment from the Clarence River, shown in Figure 8-10. While a natural levee would have existed historically, the levee was improved during flood mitigation works in the 1960's (Bewsher Consulting Pty Ltd, 2007). The low-lying area behind the natural levee would have been in the past a predominantly freshwater backswamp with limited connectivity to the main river, however artificial drainage has been constructed to allow for improved agricultural productivity.

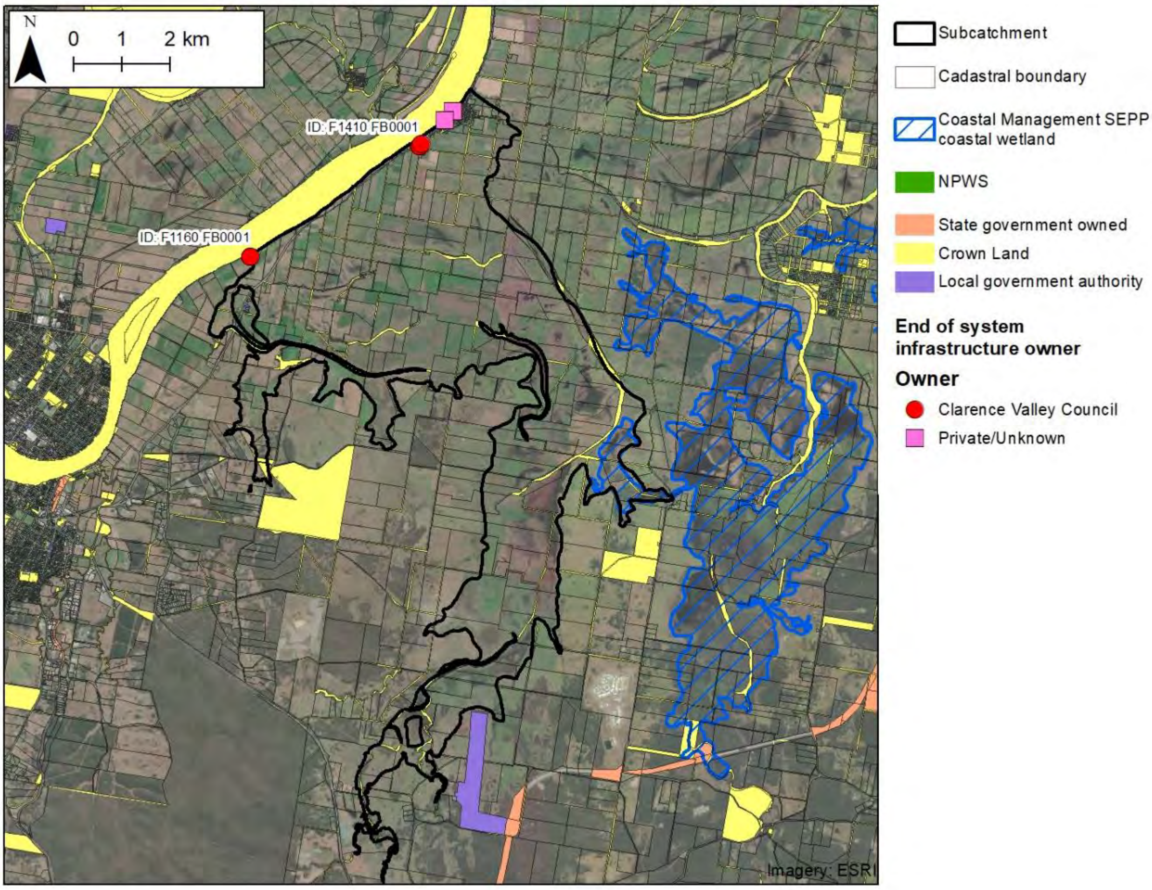

Figure 8-9: Swan Creek subcatchment land and end of system infrastructure tenure

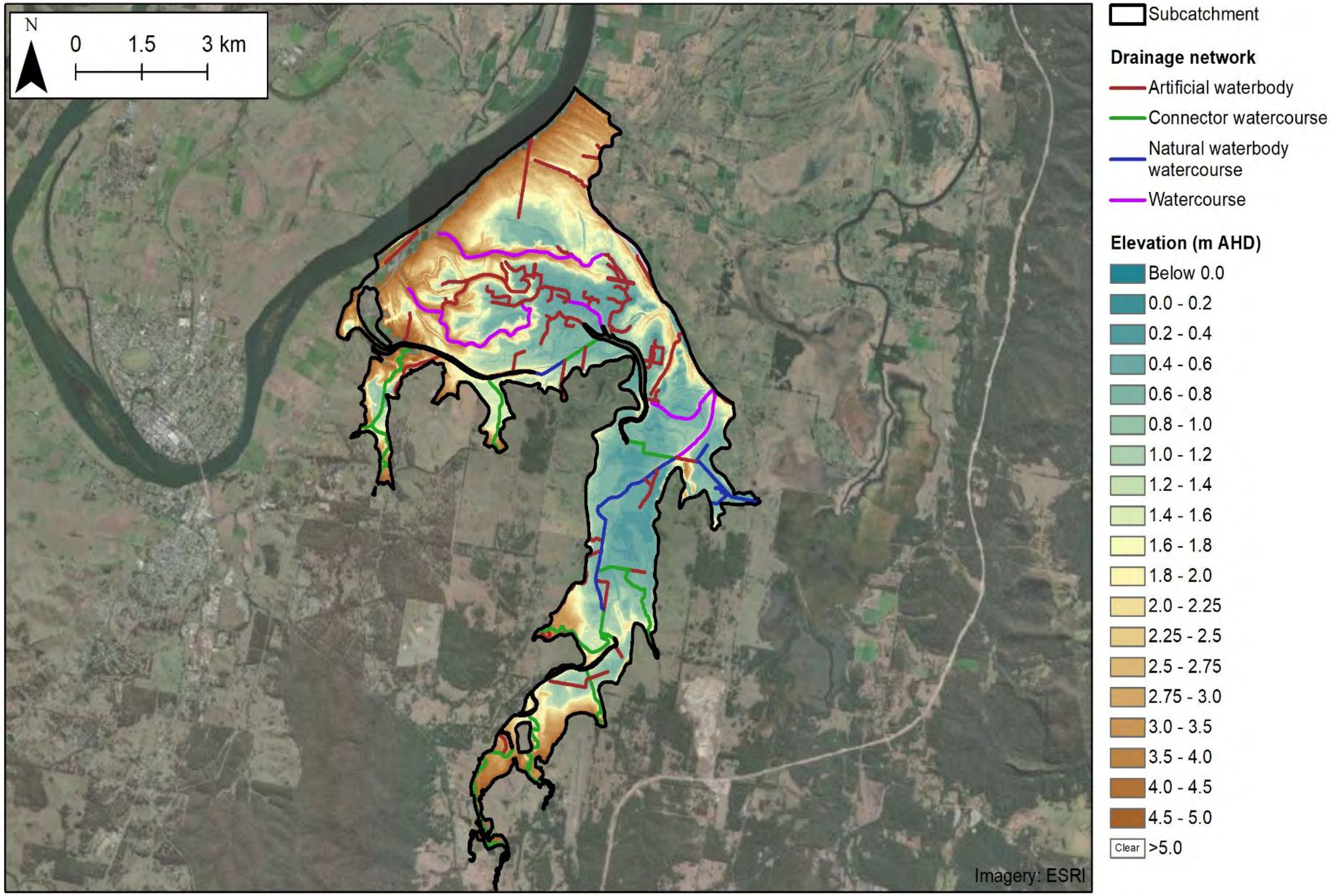

Figure 8-10: Swan Creek subcatchment elevation and drainage network

8.4.2 History of remediation

At least two (2) of the floodgates have been modified in the Swan Creek subcatchment to allow controlled tidal flushing through the drainage system, based on information provided by CVC, as shown in Figure 8-11. This includes:

- A sluice gate on floodgate ID F-1410-FB-0001. The sluice gate was not observed by WRL during 2019 field investigations, however it is assumed that the purpose of the sluice gate is to allow controlled tidal flushing and aquatic connectivity for fish passage; and
- A lifting mechanism on the Swan Creek penstocks (F-1160) which are operating to maintain water levels in Swan Creek to facilitate irrigation (Bader et al., 2018). The penstocks were upgraded in 2008 so that two (2) of the seven (7) gates operate automatically based on water levels (Clarence Valley Council, 2008).

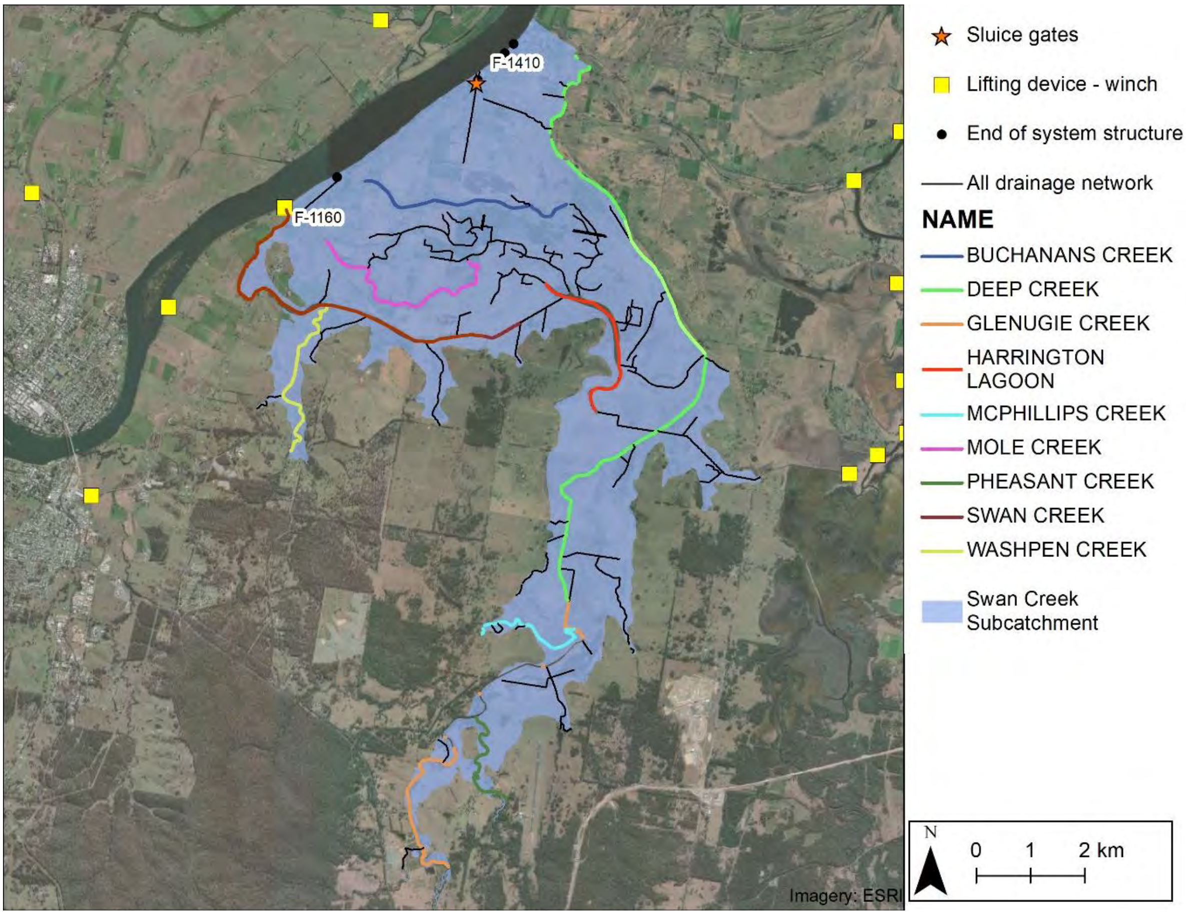

Figure 8-11: Swan Creek subcatchment including previous remediation actions

A newsletter from the Clarence Floodplain Project states that fish flaps were trialled on the Swan Creek penstocks in 2003 (Clarence Valley Council, 2003). The trial was reported to be a success, with fish returning to the creek and private landholders interested in similar modification on other floodgates. Fish flaps were not observed to be in place during field investigations completed for this study, and it is unclear whether this trial was continued when the penstocks were upgraded in 2008.

8.4.3 Prioritisation of management areas in Swan Creek subcatchment

Swan Creek is the second highest ranked subcatchment in the Clarence River floodplain with regards to acid generation, and ranked third for blackwater generation. The subcatchment has been further divided into four (4) management areas (referred to as SWC1 – SWC4) to provide additional information on the sources of acid and blackwater in the Swan Creek subcatchment. The areas have been delineated based on data availability, elevation, changes in soil acidity and drainage units.

The management areas have been prioritised for acid generation using the method described in Section 4.2. The results of the acid prioritisation are shown in Figure 8-12 and summarised in Table 8-5. The highest priority management area is SWC1, the furthest upstream in the Swan Creek subcatchment, primarily due to higher soil acidity. Management area SWC2 is the second highest priority in the middle of the subcatchment around Harrington Lagoon.

Figure 8-13 shows the management areas at Swan Creek subcatchment below the median elevation for blackwater generation (+1.9 m AHD). As elevation is a primary driver of the production of blackwater, the areas below this level typically have the greatest contribution to the risk of large scale deoxygenation. The management areas that are likely to be contributing the most to blackwater generation in the Swan Creek subcatchment are SWC1 and SWC3.

Based on the prioritisation of management areas for acid generation, and the areas below the median elevation for blackwater generation, it is suggested that management efforts to improve water quality should initially focus on management areas SWC1, SWC2 and SWC3.

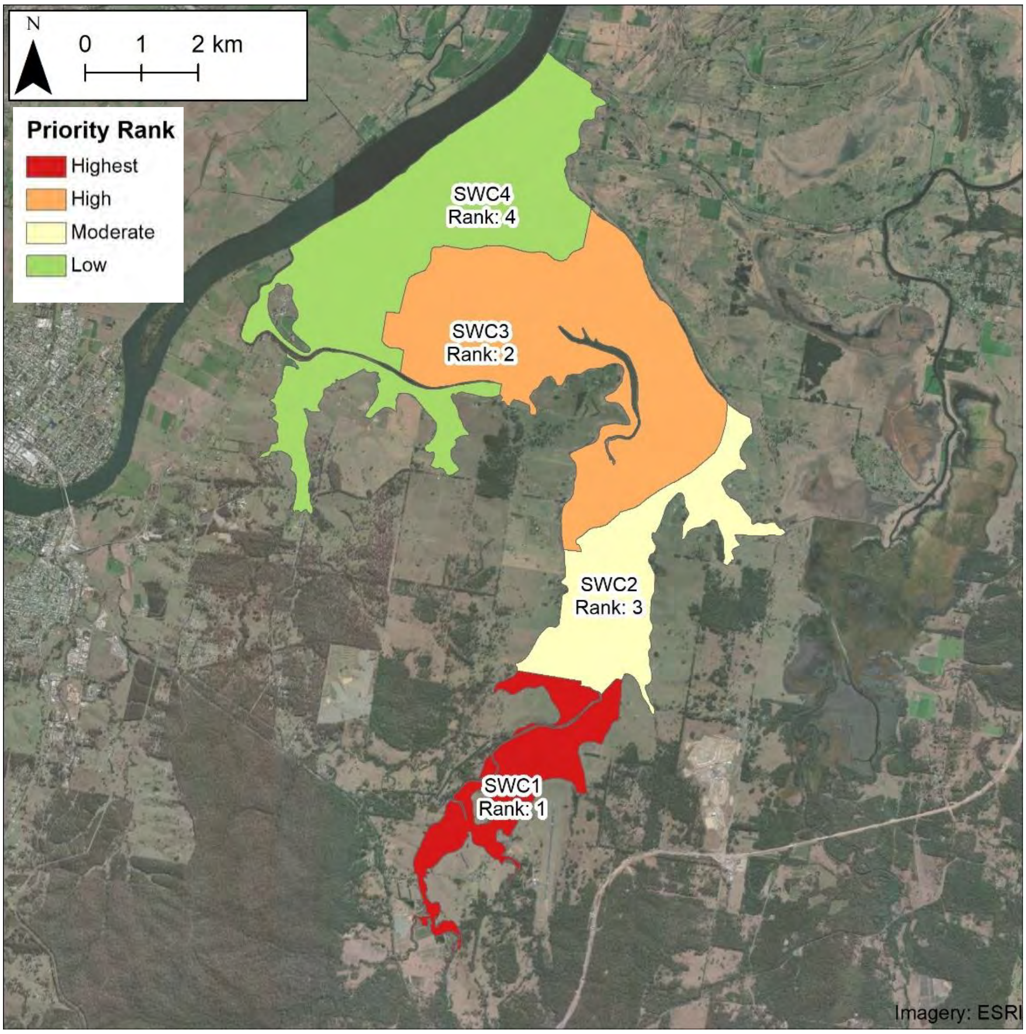

Figure 8-12: Swan Creek subcatchment management areas acid prioritisation

Table 8-5: Management area acid prioritisation of Swan Creek subcatchment

Management area	Groundwater factor	Surface water factor	Final acid factor	Final rank
SWC1	245	604	147,922	1
SWC3	65	524	34,165	2
SWC2	12	516	6,076	3
SWC4	6	420	2,707	4

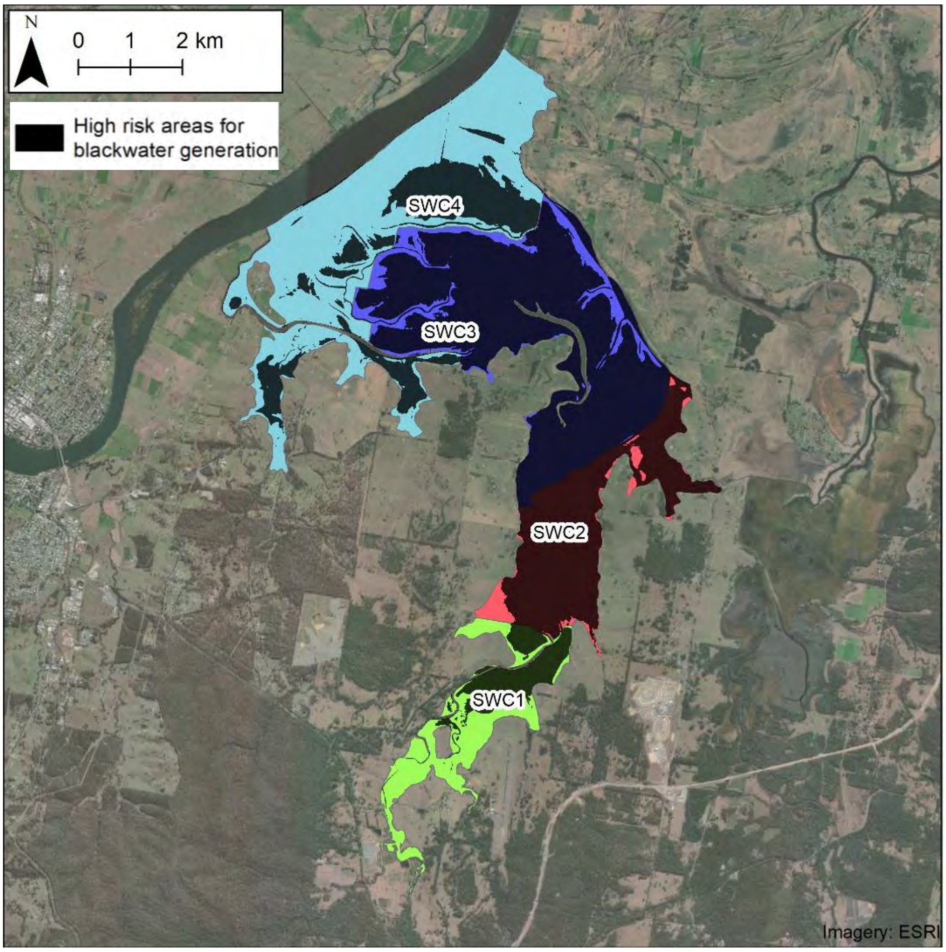

Figure 8-13: High risk areas for blackwater generation in management areas in Swan Creek subcatchment (median blackwater level 1.9 m AHD)

8.4.4 Floodplain drainage – sea level rise vulnerability

The vulnerability of the Swan Creek subcatchment to sea level rise is shown in Figure 8-14. This subcatchment will be impacted by reduced drainage, particularly in the far future, when a substantial area will be classified as medium risk. Present day land uses may be impacted by sea level rise and subject to reduced drainage in the far future, resulting in prolonged inundation times.

Both of the two (2) primary floodgates (floodgates ID F-1160-FB and F-1410-FB, shown in Figure 8-15) are identified as 'Moderately vulnerable' in the far future, meaning that downstream 95th percentile water levels (high tides) will be above the obvert of the structure. The remaining secondary structures are classified as 'Least vulnerable'.

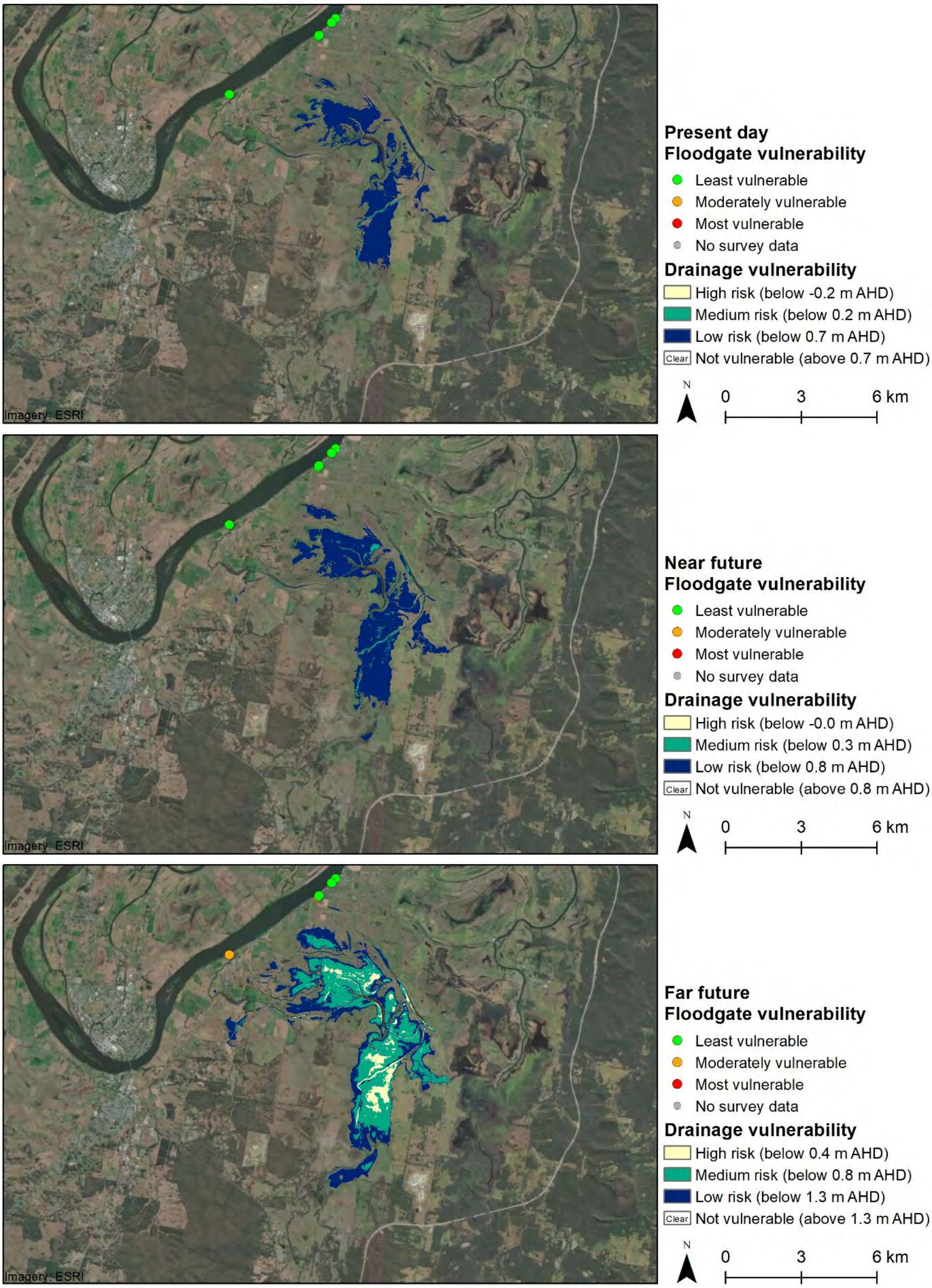

Figure 8-14: Sea level rise drainage vulnerability – Swan Creek subcatchment

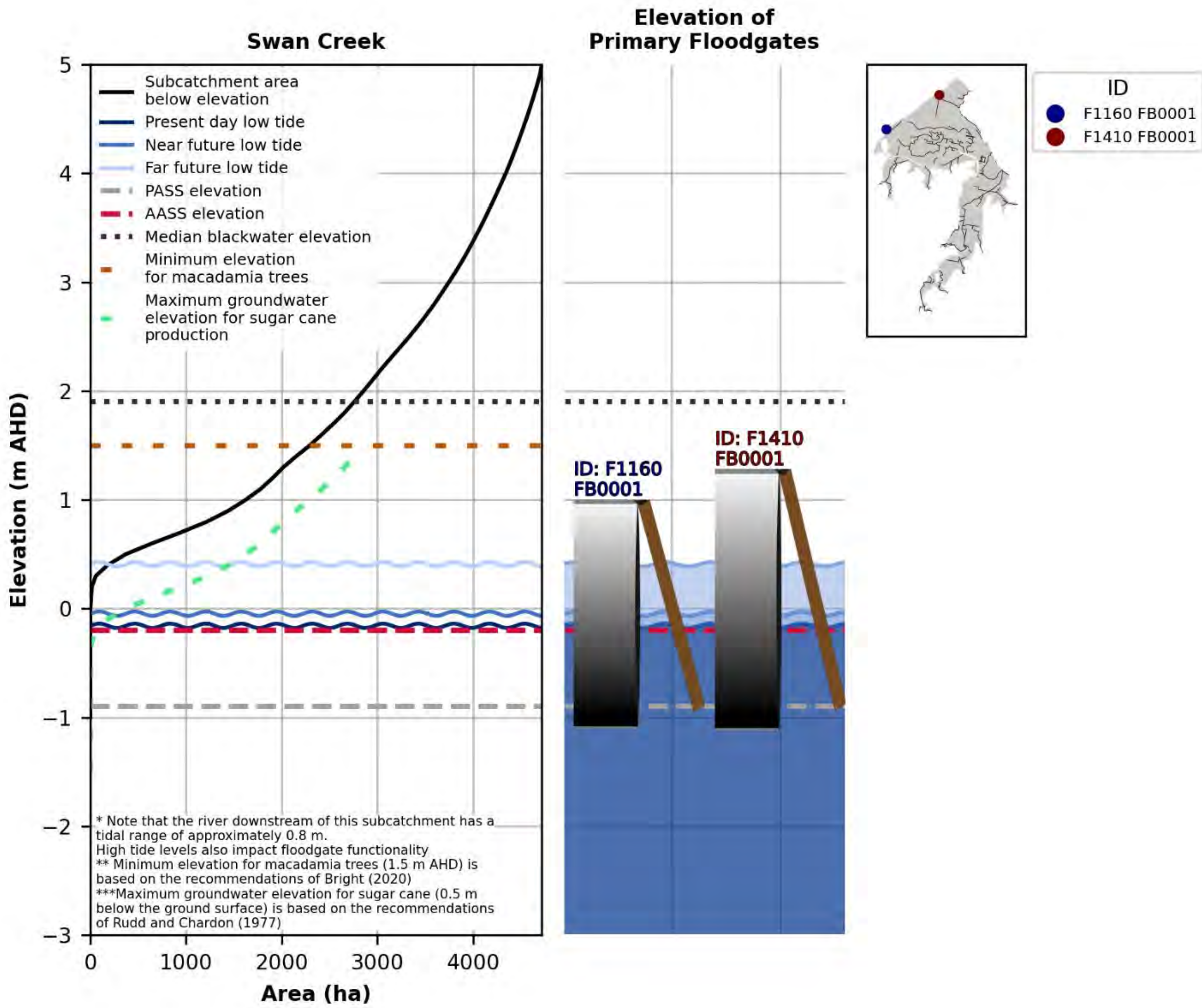

Figure 8-15: Primary floodgates and key floodplain elevations – Swan Creek subcatchment

8.4.5 Management options

Short-term management options

The main floodgates in the Swan Creek subcatchment have been previously modified to enable controlled tidal flushing, either through the installation of winches or sluice gates. It is recommended that the management of these structures be reviewed regularly and optimised to allow the maximum flushing without adversely impacting land uses. This may allow for modest improvements to overall water quality in management areas without major impacts to existing land uses.

Encouraging wet pasture management through the installation of weirs and infilling redundant paddock scale drains in both areas, would reduce the potential for acid drainage. Any plans for wet pasture management would require the cooperation and input from local landholders to ensure the resulting pasture is appropriate for their stock or needs.

Long-term management options

Future sea level rise may impact drainage and present day land uses in the Swan Creek subcatchment, particularly in low-lying management areas SWC2 and SWC3. These areas will be the most vulnerable to reduced drainage and prolonged inundation, and should therefore be targeted for restoration of natural freshwater hydrology in the low-lying backswamps. This may include infilling artificial drainage network and re-instatement of natural levees. This will encourage freshwater wetland vegetation and reduce the efficiency of the connection to the wider Clarence River, which will reduce the severity of blackwater originating from this subcatchment. Stock exclusion areas should be considered where possible to minimise erosion along the banks of ponded water. Broadscale management changes in this subcatchment will need to consider, and have a plan to mitigate potential social, cultural and economic impacts to local landholders.

A summary of the recommended management options for the Swan Creek subcatchment is provided in Table 8-6.

Table 8-6: Summary of management options for Swan Creek subcatchment

		Effectiveness at improving:		
Timeframe	**Strategy**	**Wetland habitat and fish passage**	**Impacts of ASS**	**Impacts of blackwater**
Short-term	Actively manage floodgates	Moderate	Small	Negligible
Short-term	Wet pasture management	None	Moderate	Moderate
Long-term	Localised freshwater backswamps	High	High	High

8.5 Gulmarrad/East Woodford Island subcatchment

Acid priority rank:	**3**
Blackwater priority rank:	**10**
<u>Infrastructure</u>	
Approximate waterway length (km)	48
# Privately owned end of system structures	6
# Publicly owned end of system structures	18
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	F-2200-FB-0001, F-2300-FP0003
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	-1.4 to -0.6
Approximate AASS elevation (m AHD)	0.5
Approximate PASS elevation (m AHD)	-0.7
Median blackwater elevation (m AHD)	0.9
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0.0
Far future low level (m AHD)	0.5
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	23.7
Saltmarsh (km)	3.5
Seagrass (km)	14.9
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	0.1
<u>Land use</u>	
Total floodplain area (ha)	1,647
Classified as conservation and minimal use (ha (%))	20 (1%)
Classified as grazing (ha (%))	307 (19%)
Classified as forestry (ha (%))	1 (0%)
Classified as sugar cane (ha (%))	540 (33%)
Classified as horticulture (ha (%))	5 (0%)
Classified as other cropping (ha (%))	486 (29%)
Classified as urban/industrial/services (ha (%))	108 (7%)
Classified as marsh/wetland (ha (%))	92 (6%)
Other (ha (%))	88 (5%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$2,500,000
Average land value above 0.9 m AHD ($/ha)	$8,200
Average land value below 0.9 m AHD ($/ha)	$6,800

8.5.1 Site description

The Gulmarrad/East Woodford Island subcatchment is located on the South Arm of the Clarence River, upstream from Maclean, shown in Figure 8-16. Major agricultural land uses in the subcatchment include a mix of cropping, sugar cane, and grazing. The eastern side of the subcatchment (Gulmarrad) consists mainly of high land on the banks of the river, with low-lying backswamps that have been artificially drained. The western side of the subcatchment (East Woodford Island) has a main natural watercourse (Camp Creek) that runs north-south with natural levees, and an artificial drainage network that facilitates present day land uses. The drainage and topography of the subcatchment is shown in Figure 8-17.

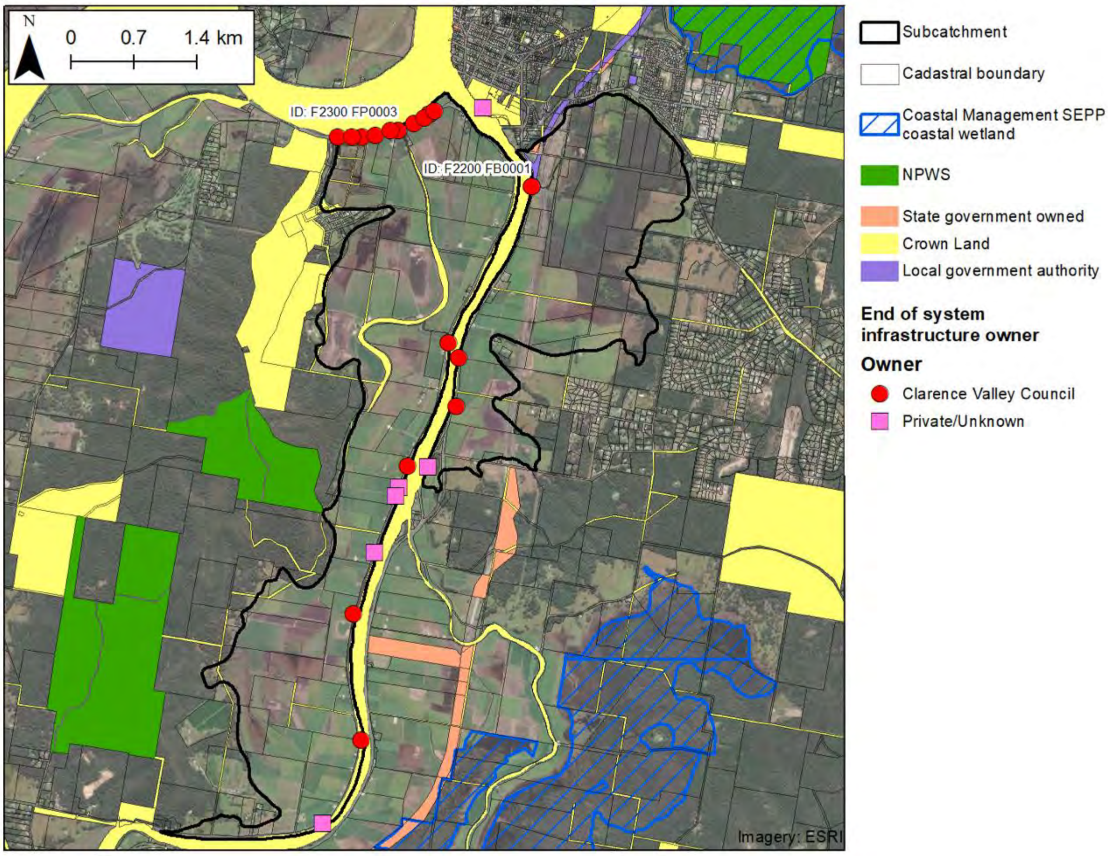

Figure 8-16: Gulmarrad/East Woodford Island subcatchment land and end of system infrastructure tenure

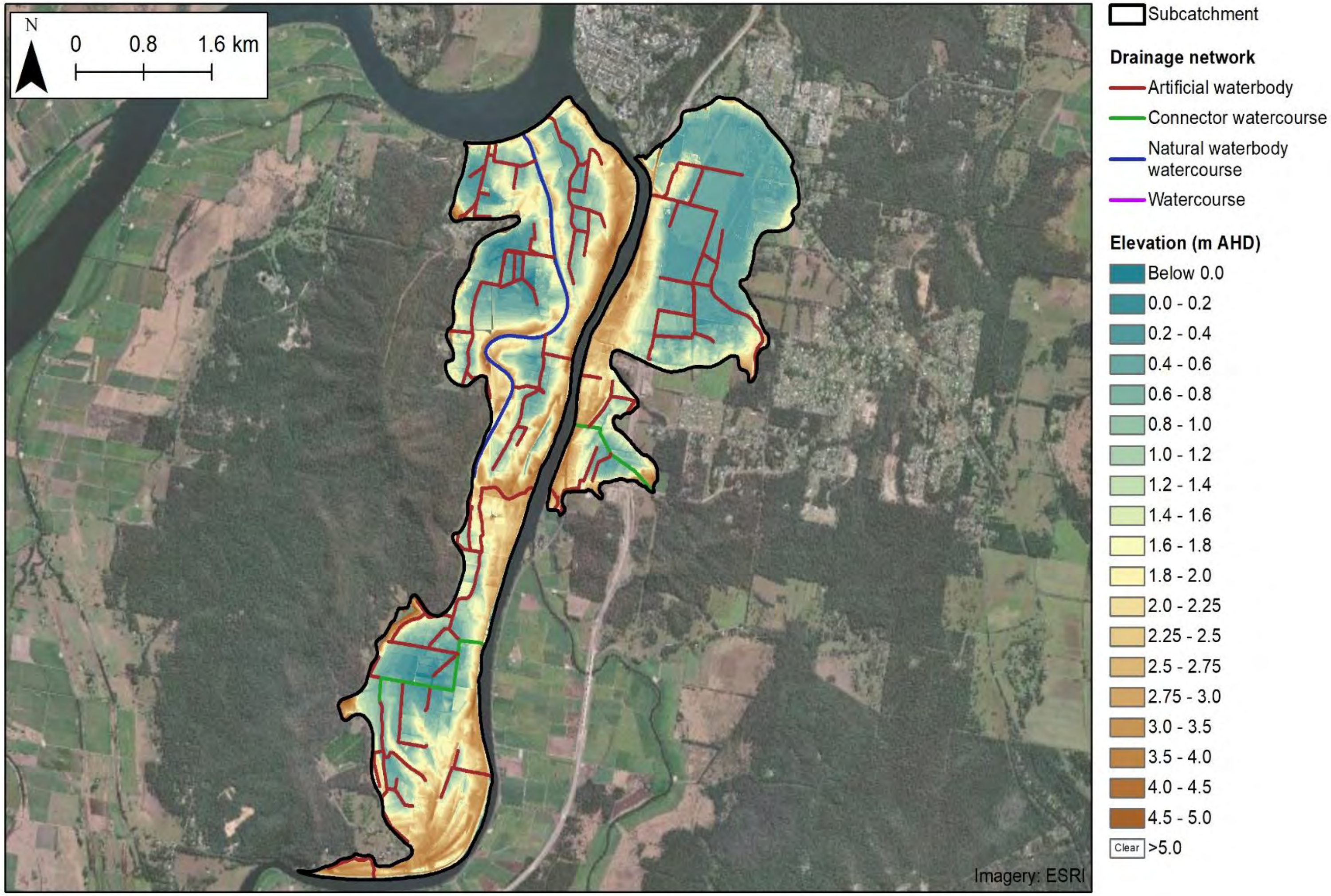

Figure 8-17: Gulmarrad/East Woodford Island subcatchment elevation and drainage network

8.5.2 History of remediation

Three (3) floodgates have been modified in the Gulmarrad/East Woodford Island subcatchment, as shown in Figure 8-18. This includes:

- Winches on floodgate ID F-2300-FP-0003 at the end of Camp Creek and floodgate ID F-2340-FB-0001 on a drain in management area GEW2 (shown in Figure 8-19). The winches on these gates can open all the floodgates; and
- A vertical lifting mechanism on the right bank gate of floodgate ID F-2200-FB-0001 on Edwards Creek, shown in Figure 8-20.

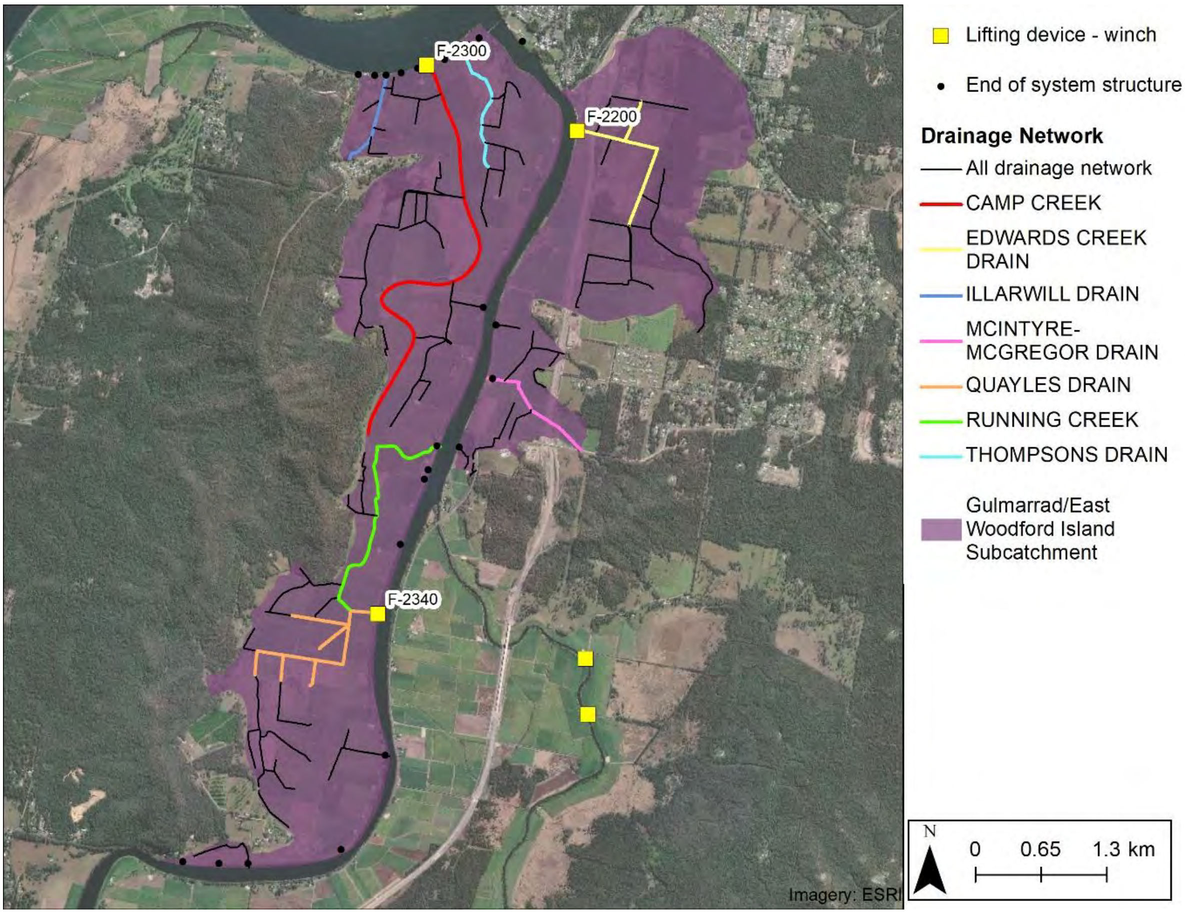

Figure 8-18: Gulmarrad/East Woodford Island subcatchment including previous remediation actions

A newsletter from the Clarence Floodplain Project in 2005 (Clarence Valley Council, 2005) suggests that stock exclusion (fencing) of an acid scald was completed to assist in recovery in the Edwards Creek Drain area (management area GEW3 (see Figure 8-21), upstream of floodgate ID F-2200-FB-0001), and a drainage management plan was developed.

Sugar cane farms in the Clarence River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Gulmarrad/East Woodford Island subcatchment were not obtained, cane farms typically implement the following ASS management actions:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

Figure 8-19: Floodgate ID F-2340-FB-0001 fitted with winch mechanism

Figure 8-20: Floodgate ID F-2200-FB-0001 with vertical lifting mechanism on the right bank floodgate

8.5.3 Prioritisation of management areas in Gulmarrad/East Woodford Island subcatchment

The Gulmarrad/East Woodford Island is the third highest ranked subcatchment in the Clarence River floodplain with regards to acid generation potential. The subcatchment has been further divided into three (3) management areas (referred to as GEW1 to GEW3) to provide additional information on the sources of acid. The areas have been delineated based on data availability, elevation, changes in soil acidity and drainage units.

The management areas have been prioritised for acid generation using the method described in Section 4.2. The results of the acid prioritisation are shown in Figure 8-21 and summarised in Table 8-7. The highest priority management area is GEW3 near Gulmarrad primarily due to higher soil acidity. Management area GEW1 is the lowest priority, however this is based on a single soil profile in which acidity was not observed. Additional investigation of soil acidity would confirm a low acid risk from management area GEW1.

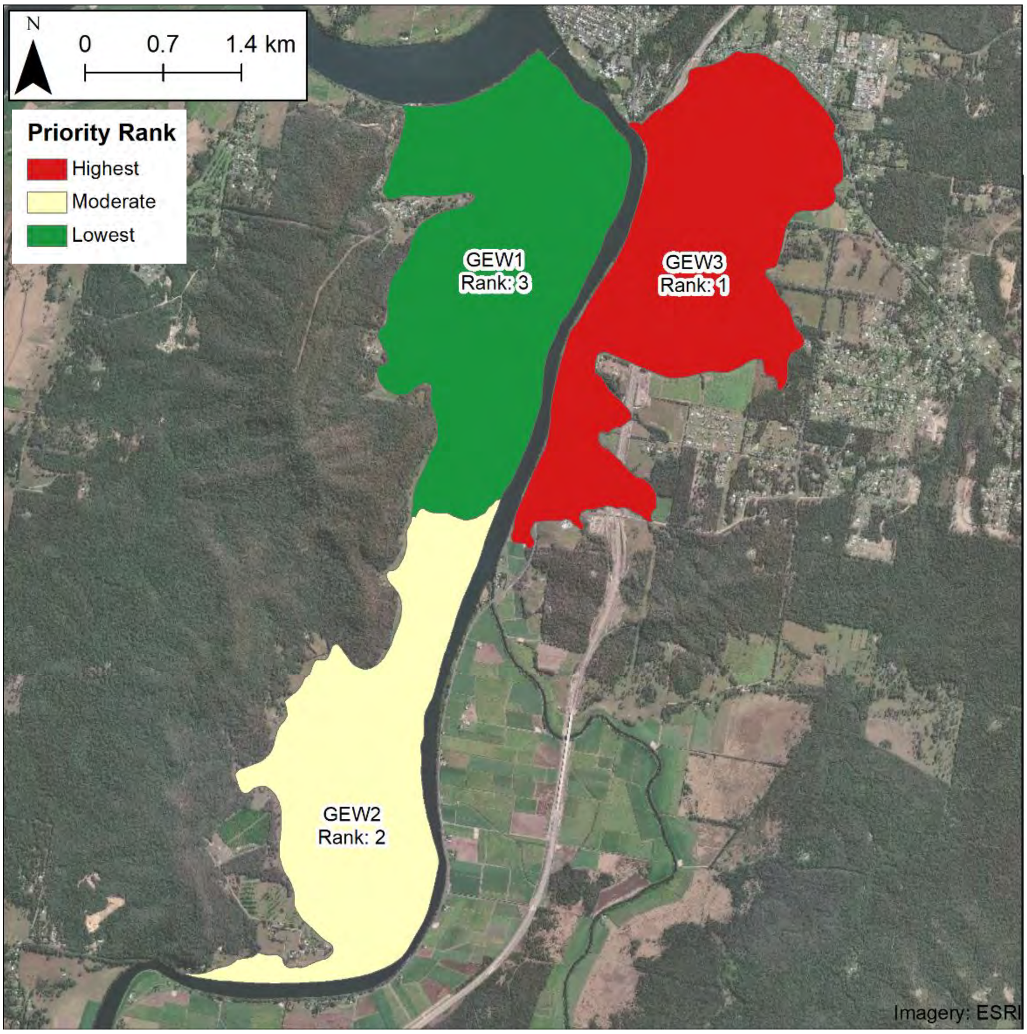

Figure 8-21: Gulmarrad/East Woodford Island subcatchment management areas acid prioritisation

Table 8-7: Management area acid prioritisation of Gulmarrad/East Woodford Island subcatchment

Management Area	Groundwater Factor	Surface Water Factor	Final Acid Factor	Final Rank
GEW3	199	603	120,248	1
GEW2	20	611	12,286	2
GEW1	0.1	728	53	3

The Gulmarrad/East Woodford Island subcatchment ranked 11th for blackwater generation, so it is recommended that the management strategies in this subcatchment primarily focus on reducing acid discharges associated with ASS. Blackwater generation has not been considered in the prioritisation of management areas in this subcatchment.

8.5.4 Floodplain drainage - sea level rise vulnerability

Figure 8-22 summarises the sea level rise vulnerability in the Gulmarrad/East Woodford Island subcatchment. There are localised areas presently classified as low risk both in East Woodford Island and Gulmarrad. By the far future (~2100), many of these locations will become high risk. Drainage in this subcatchment will be impacted substantially in the near to far future due to relatively low elevation topography, which may affect the productivity and feasibility of present day land uses (e.g. sugar cane and grazing).

The elevation of primary floodgates compared to key elevations across the subcatchments is shown in Figure 8-23. Seven (7) floodgates will be classified as 'Most vulnerable' in the far future, including primary structure F-2300-FP-0003 which is also 'Moderately vulnerable' in the near future. Five (5) other floodgates will be classified as 'Moderately vulnerable' in the far future, including the other primary floodgate F-2200-FB-0001.

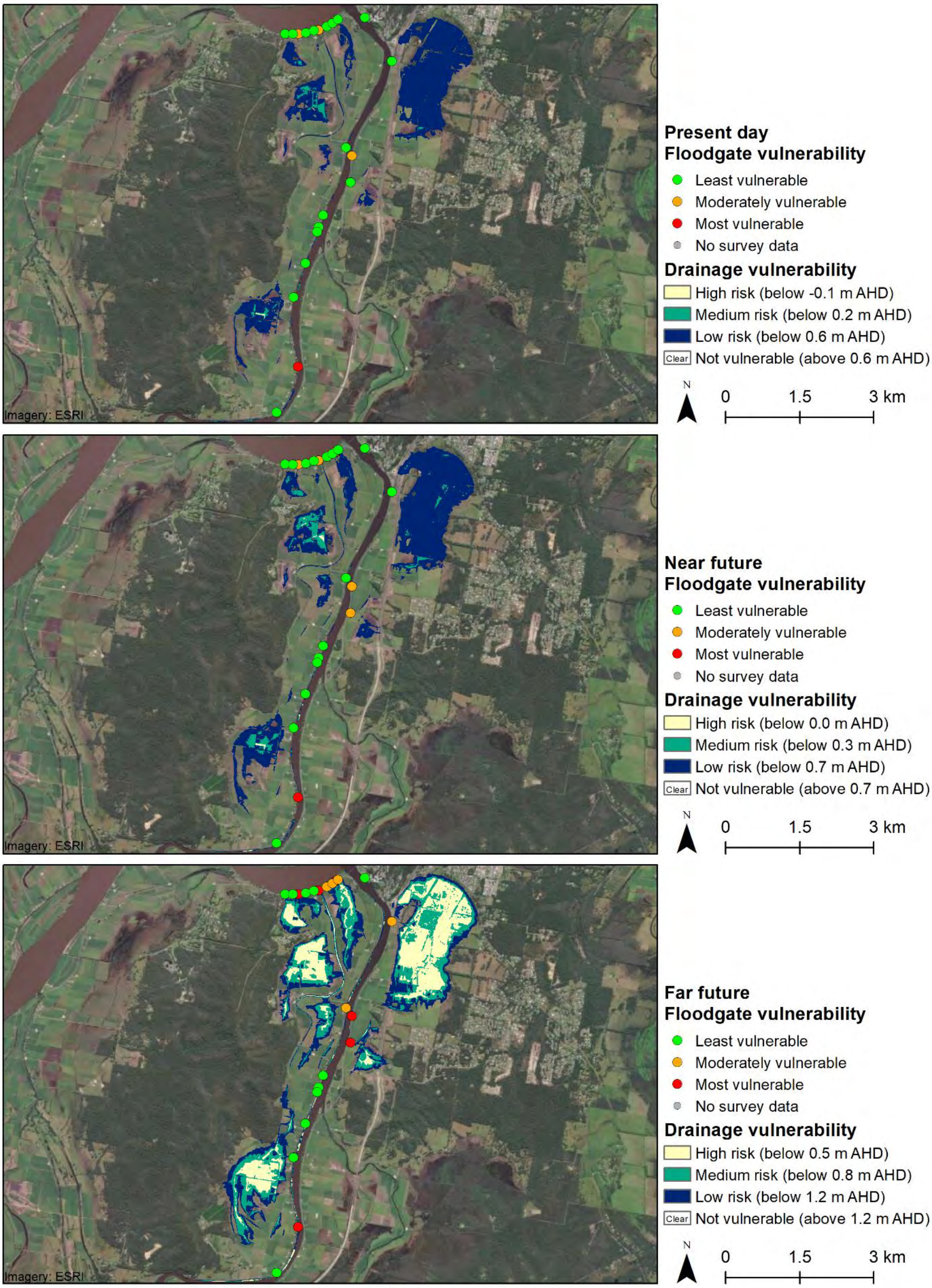

Figure 8-22: Sea level rise drainage vulnerability – Gulmarrad/East Woodford Island subcatchment

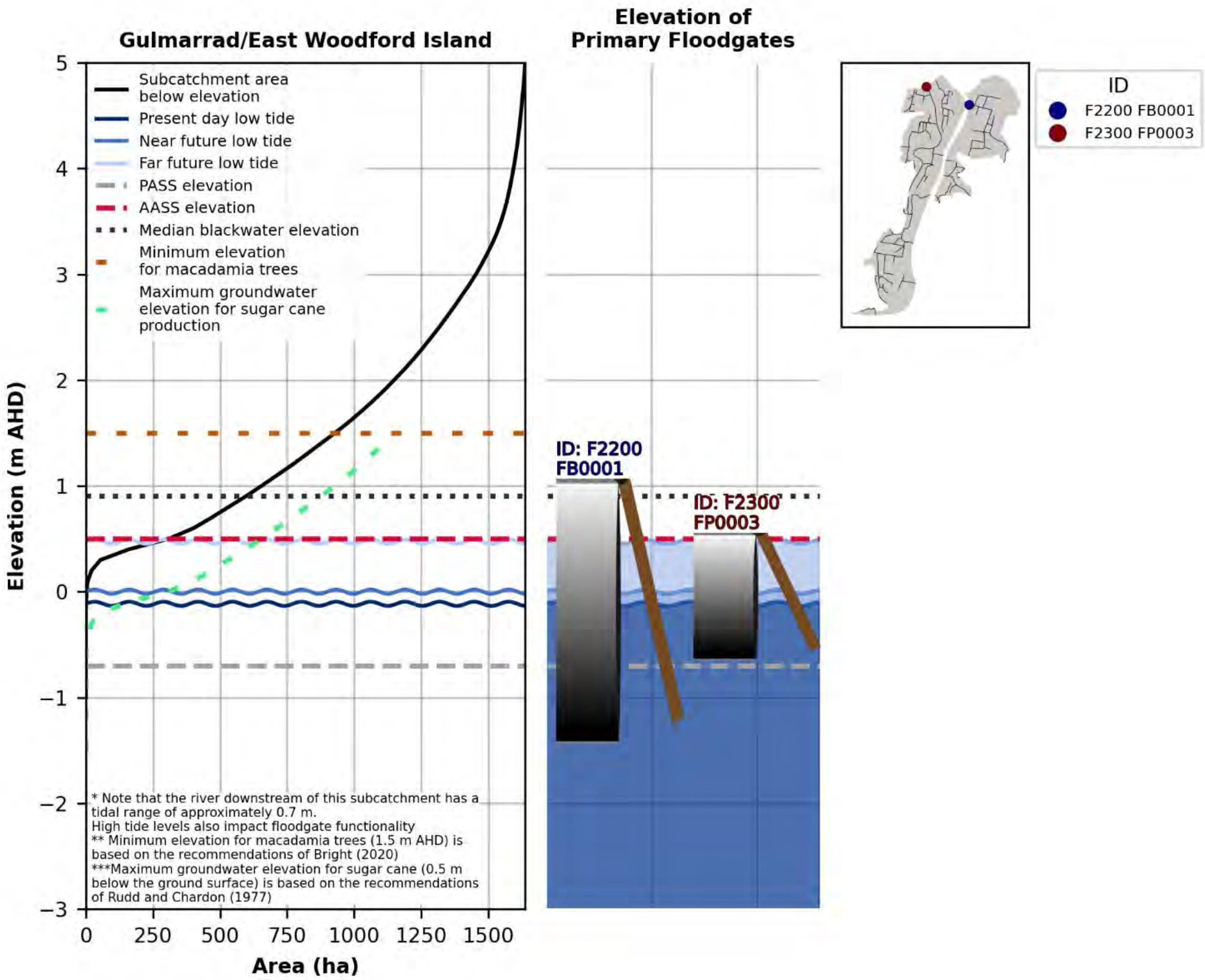

Figure 8-23: Primary floodgates and key floodplain elevations – Gulmarrad/East Woodford Island subcatchment

8.5.5 Management options

Short-term management options

Tidal flushing has already been implemented on the major floodplain infrastructure in this subcatchment. The management of these modified floodgates should be reviewed to optimise tidal flushing during non-flood periods without impacting current land uses. In addition, the installation of dropboard weirs in low lying areas actively used for grazing could be considered to encourage wet pasture management with the aim of reducing both acid and blackwater drainage. Any plans for altered drainage and wet pasture management would require the cooperation and input from local landholders to ensure the resulting pasture is appropriate for their stock or needs.

Pumps have also been observed on some properties in this management area to dewater upstream floodplain areas. Pumping may result in increasing groundwater draw down and can increase ASS oxidation and acidic discharges. Management and limiting pumping would reduce potential soil oxidation and acid export.

Long-term management options

High soil acidity was observed in management area GEW3, in the same area that is identified as high risk of reduced drainage under sea level rise (below the 5^{th} percentile water level in the far future, see Figure 8-22), east of the Pacific Highway. This area should be targeted for restoration of natural hydrology to reduce the mobilisation of acid. This may include infilling all secondary drainage channels and re-design of the major drainage network to limit drainage while still providing adequate flood mitigation to upstream areas. Water retention in this area would prevent further acidification, reduce groundwater drawdown, encourage water tolerant vegetation, and reduce blackwater discharges from low elevation backswamp areas. Note that any changes in hydrology will require extensive studies into the potential impacts to flooding and land uses.

A summary of the recommended management options for the Gulmarrad/East Woodford Island subcatchment including indicative costs is provided in Table 8-8.

Table 8-8: Summary of management options for Gulmarrad/East Woodford Island subcatchment

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Actively manage floodgates	Moderate	Small	Negligible
Short-term	Wet pasture management	None	Moderate	Moderate
Long-term	Localised freshwater backswamps	High	High	High

8.6 Shark Creek subcatchment

Acid priority rank:	**4**
Blackwater priority rank:	**5**
Infrastructure	
Approximate waterway length (km)	67
# Privately owned end of system structures	0
# Publicly owned end of system structures	20
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID)	F-2130-FP-0001, F-2150-FP-0001,F-2210-FB-0001, ,F-2230-FP-0001
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.1 to -0.4
Approximate AASS elevation (m AHD)	0.2
Approximate PASS elevation (m AHD)	-0.4
Median blackwater elevation (m AHD)	1.1
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0.0
Far future low level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	28.6
Saltmarsh (km)	9.3
Seagrass (km)	19.8
Mangroves (km)	0.1
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	4,363
Classified as conservation and minimal use (ha (%))	1,129 (26%)
Classified as grazing (ha (%))	757 (17%)
Classified as forestry (ha (%))	127 (3%)
Classified as sugar cane (ha (%))	145 (3%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	572 (13%)
Classified as urban/industrial/services (ha (%))	70 (2%)
Classified as marsh/wetland (ha (%))	1,212 (28%)
Other (ha (%))	352 (8%)
Land values	
Estimated total primary production value ($/year)	$1,300,000
Average land value above 1.1 m AHD ($/ha)	$4,300
Average land value below 1.1 m AHD ($/ha)	$2,200

8.6.1 Site description

The Shark Creek subcatchment discharges to the South Arm of the Clarence River approximately 2 km north of Tyndale. The subcatchment is separated from the Clarence River to the west by a natural levee system, and Shark Creek itself also has a natural, low (1.5 to 2 m AHD) levee system along its banks. The majority of the subcatchment is low-lying (< 1 m AHD), with substantial areas situated below +0.5 m AHD (Figure 8-25). The higher area between the Pacific Highway (the highway is shown in pink in Figure 8-24) and the South Arm of the Clarence River, is predominantly used for sugar cane. The upper Shark Creek area is largely undeveloped and has minimal artificial drainage.

The drainage of Shark Creek likely began in the early 1900's, although major artificial drains, levees and floodgates were constructed in 1966 by the Council (Tulau, 1999a; Tulau, 1999b). While the hydrology of the lower sections of the subcatchment has been heavily modified and drained, the upstream sections (upstream/south of the southern floodgate in Figure 8-24) is a predominantly natural freshwater wetland area covered in native vegetation (mapped as Coastal Management SEPP coastal wetlands) and not used for agriculture.

Shark Creek was recognised as an ASS hotspot in the Clarence River floodplain by Tulau (1999a). A fish kill event was recorded in Shark Creek in the DPI fish kill database in 2011 and the subcatchment was identified as a key source of blackwater in the Clarence River floodplain by Walsh et al. (2004).

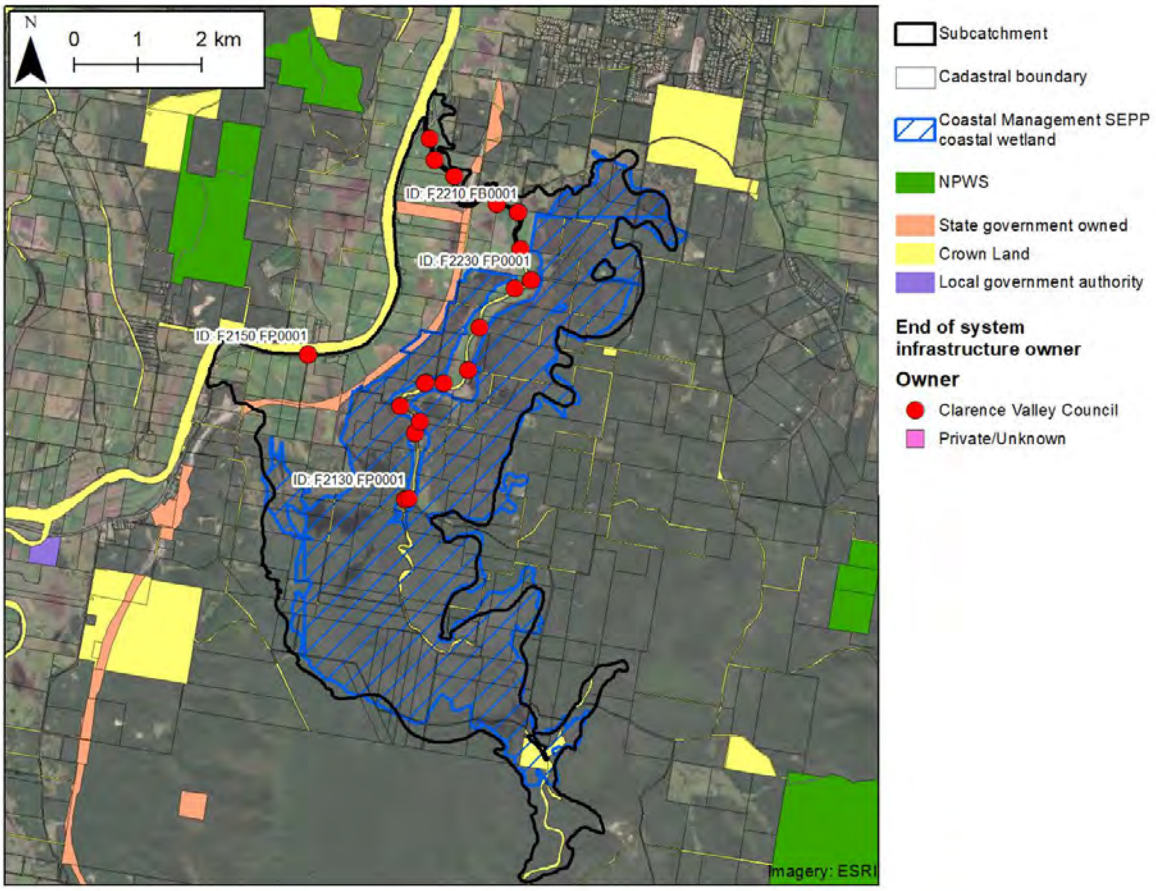

Figure 8-24: Shark Creek subcatchment - land and end of system infrastructure tenure

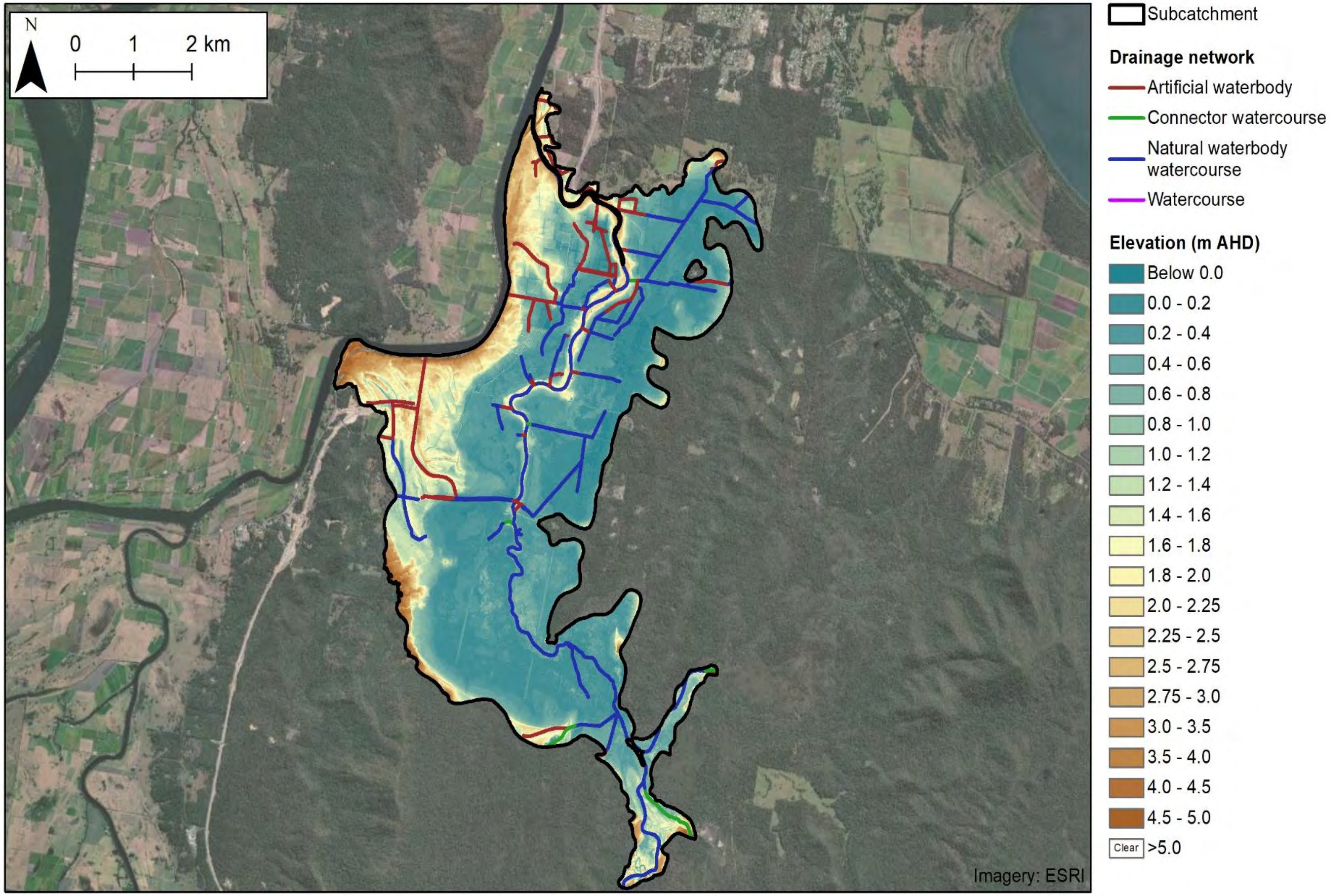

Figure 8-25: Shark Creek subcatchment elevation and drainage network

8.6.2 History of remediation

Shark Creek was identified as an ASS hotspot in NSW by Tulau (1999a) and has received state government funding to address acid drainage. This has included modifying three (3) of the major floodgates with lifting devices (floodgate ID F-2210-FB-0001, F-2220-FP-0001 and F-2230-FP-0001), the locations shown in Figure 8-26.

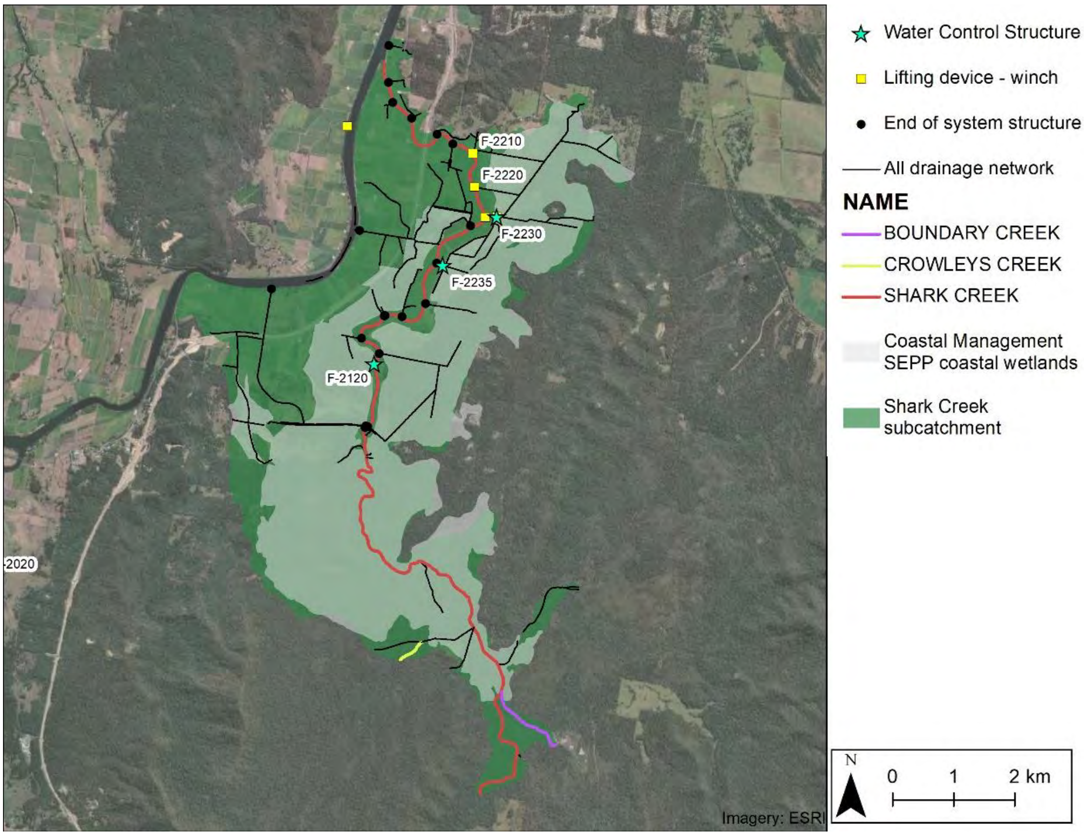

Figure 8-26: Shark Creek subcatchment including previous remediation actions

Trial openings of the main floodgate on Maloneys Drain (floodgate ID F-2230-FP-0001) were completed in 2001, prior to the installation of the water control structure on the same drain. The trial showed that opening the floodgates was associated with higher salinity levels, and lower concentrations of sulfates and metals (Johnston et al., 2005b). However, Johnston et al. (2002) noted that the floodgate opening can actually cause an increase in acid flux in this drainage system, due to the very high hydraulic conductivity which allows sufficient groundwater drainage on ebb tides during which acid discharge occurs. This was observed during short-term (4 days) trials of floodgate opening. Hence it was suggested that water control structures such as weirs be used in conjunction with floodgate reopening. This would reduce the acid seepage from the groundwater table, while allowing benefits of flushing achieved through tidal exchange (assuming weir levels are below high tide water levels).

The three (3) water control structures in the Shark Creek subcatchment were identified as “head and discharge” structures in the CVC dataset, which effectively act as adjustable weirs, such as the one on Maloneys Drain (F-2230-FH) (Figure 8-27). These structures maintain a high water table to reduce groundwater drawdown and drainage of acid upstream. Johnston et al. (2004) showed that the weir on

Maloneys Drain reduced groundwater acid seepage by around 65 - 70%, although acidic discharges from surface water flows (e.g. when the weir is overtopped) are largely unaffected.

Figure 8-27: Water control structure F-2230-FH on Maloneys Drain (crest level ~0.2 m AHD)

A substantial portion of the Shark Creek subcatchment is mapped as Coastal Management SEPP coastal wetlands under the State Environmental Planning Policy (SEPP), also shown in Figure 8-26. This classification means that the area is subject to more stringent development controls under state government legislation.

Sugar cane farms in the Clarence River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Shark Creek subcatchment were not obtained, cane farms typically implement the following ASS management actions:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.6.3 Floodplain drainage - sea level rise vulnerability

The Shark Creek subcatchment is low-lying and is likely to be impacted by reduced drainage due to sea level rise as shown in Figure 8-28 and Figure 8-29. With the exception of the levees around Shark Creek, the majority of the area east of the Pacific Highway will be classified as medium risk (below +0.5 m AHD) in the far future. Many of the major floodgates east of the highway will also become increasingly vulnerable as sea levels continue to rise and tidal elevations increase, with primary structures F-2130-FP-0001 and F-2230-FP-0001 classified as 'Most vulnerable' in the far future.

While a majority of this area is already classified and protected as a Coastal Management SEPP coastal wetland (see Figure 8-26), some of it is used for grazing or sugar cane. Agricultural productivity in this subcatchment may be affected by sea level rise.

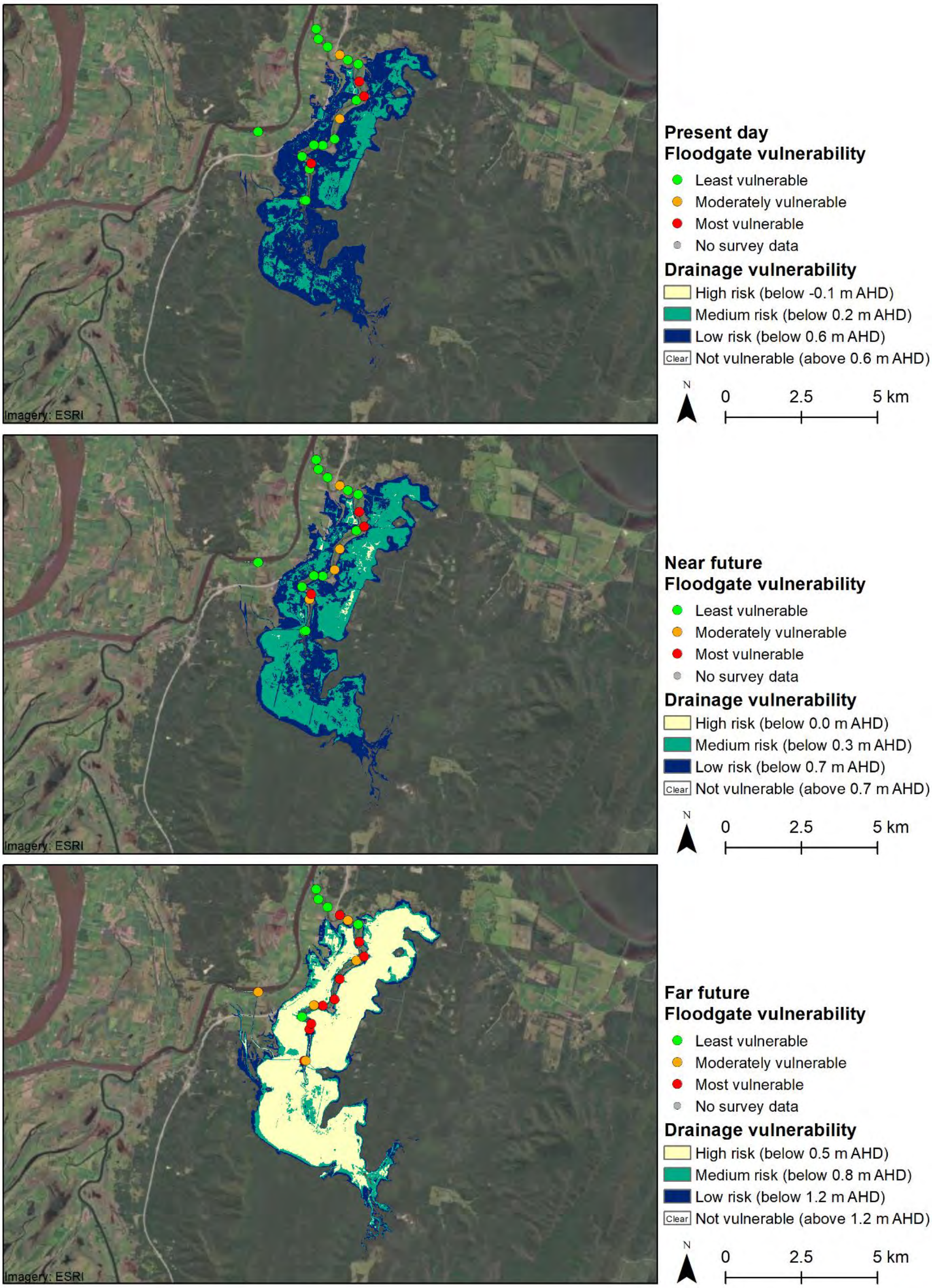

Figure 8-28: Sea level rise drainage vulnerability – Shark Creek subcatchment

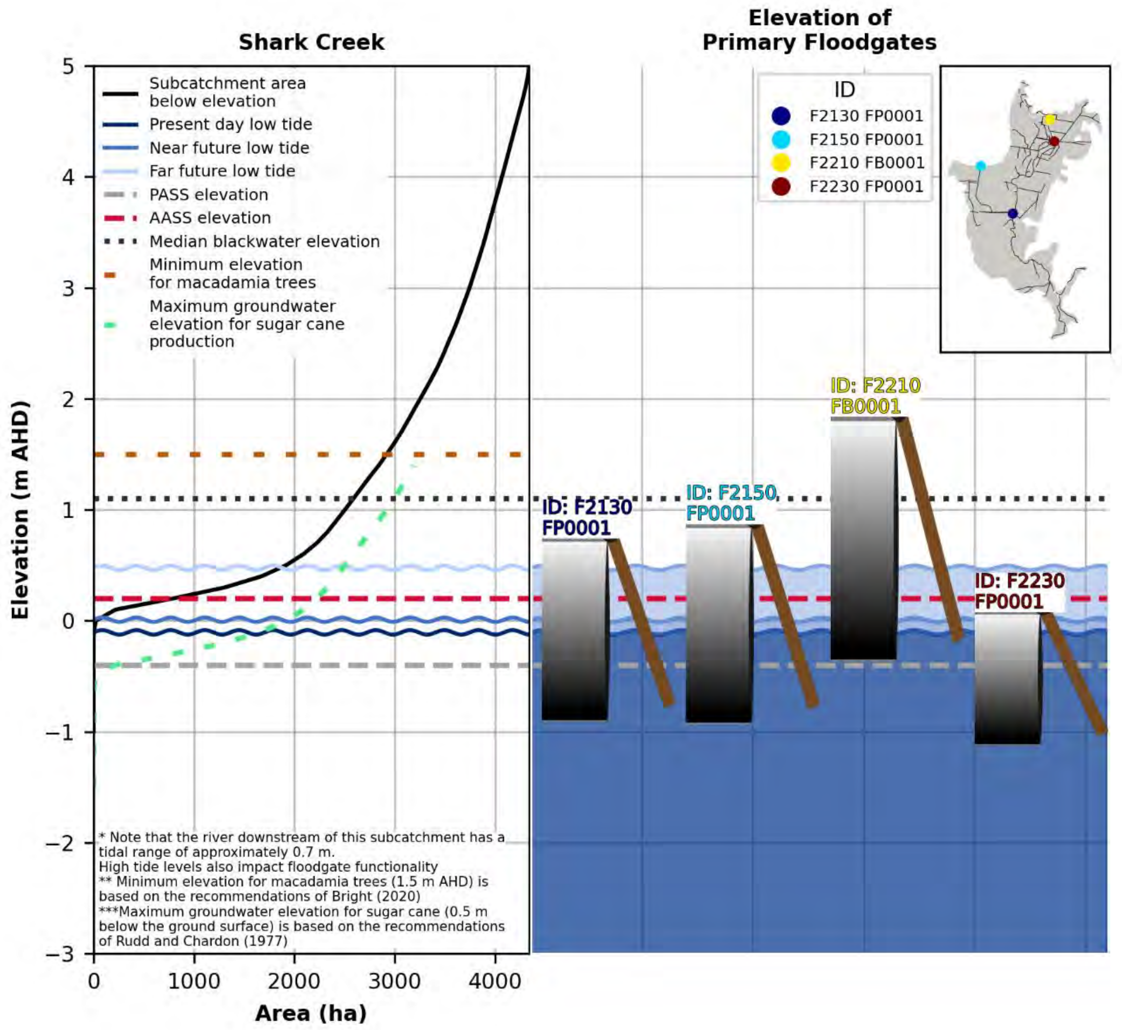

Figure 8-29: Primary floodgates and key floodplain elevations – Shark Creek subcatchment

8.6.4 Management options

Short-term management options

As discussed in Section 8.6.2, water control structures (weirs) have been installed on at least three (3) drains in the Shark Creek subcatchment, and have been shown to be effective at reducing acidic groundwater drainage (Johnston et al., 2004). This could be expanded to additional drains to further manage acid discharges. This strategy should focus on drains that connect into Shark Creek but also drain areas identified within Coastal Management SEPP coastal wetlands. This may be able to be combined with opening of downstream floodgates (or installation of buoyancy gates) to allow flushing without excessive groundwater drainage. In addition, the operation of the floodgates in this subcatchment should be reviewed and assessed to investigate whether additional tidal flushing could be implemented (through floodgate removal or modification). Any changes to the operation of floodgates will need to consider the impacts on existing land uses, and be completed with the cooperation of local landholders.

Management and maintenance of the Coastal Management SEPP coastal wetlands should also be supported. This may include support for private landholders to manage these areas.

Long-term management options

Figure 8-28 shows that the Shark Creek subcatchment will be affected by reduced drainage in the near to far future, which may impact present day land uses and productivity. Low elevation areas should be targeted for remediation of natural estuarine hydrology through land use changes, drain infilling, and redesigning the drainage system and drainage infrastructure.

Shark Creek would have naturally been a freshwater backswamp due to the natural levees situated on the creek banks. This ecosystem could be restored through infilling artificial drainage networks and re-instating natural levees (or permanently closing floodgates). This would allow significant freshwater retention on the low backswamp areas that would prevent groundwater drawdown and acid discharge, and substantially reduce the risk of blackwater runoff from this subcatchment. By facilitating prolonged drainage and an increased time of inundation, carbon cycle processes that occur when organic matter decomposes would be able to be completed, which would substantially reduce the impact of blackwater from this subcatchment on Shark Creek and the greater Clarence River estuary.

Alternatively, the artificial drainage network could be redesigned to a shallower, wider drainage network and floodgates removed. This would encourage tidal flushing of the floodplain and salt tolerant wetland species. The tidal inflows will assist in buffering acidic discharges and reduced groundwater drainage in the subcatchment, and the change in vegetation will reduce the blackwater risk. This may be more readily implementable if agricultural uses of the elevated levee bank areas continue, which require the drainage networks to be maintained. Broadscale management changes in this subcatchment will need to consider, and have a plan to mitigate potential social, cultural and economic impacts to local landholders.

A summary of the recommended management options for the Shark Creek subcatchment is provided in Table 8-9.

Table 8-9: Summary of management options for Shark Creek

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Floodgate modification	Moderate	Small	Negligible
Short-term	Water retention structures	None	Moderate	Moderate
Long-term	Restoration of natural hydrology	Moderate	High	High

8.7 Taloumbi/Palmers Channel subcatchment

Acid priority rank:	**5**
Blackwater priority rank:	**4**
Infrastructure	
Approximate waterway length (km)	140
# Privately owned end of system structures	1
# Publicly owned end of system structures	9
# End of system structures within coastal wetlands	3
# Publicly owned end of system structures within coastal wetlands	3
Primary floodplain infrastructure (ID)	F-2690-FP-0001, F-2700-FP-0001, F-2730-FP-0001, F-2740-FP-0001, F-2750-FP-0001, F-2760-FP-0001, F-2770-FP-0001, F-2780-FP-0001
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.1 to -0.4
Approximate AASS elevation (m AHD)	-0.4
Approximate PASS elevation (m AHD)	Insufficient information
Median blackwater elevation (m AHD)	0.9
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	-0.1
Far future low level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	12.6
Saltmarsh (km)	Within subcatchment
Seagrass (km)	2.6
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	4,572
Classified as conservation and minimal use (ha (%))	437 (10%)
Classified as grazing (ha (%))	1,772 (39%)
Classified as forestry (ha (%))	1 (0%)
Classified as sugar cane (ha (%))	1,475 (32%)
Classified as horticulture (ha (%))	50 (1%)
Classified as other cropping (ha (%))	71 (2%)
Classified as urban/industrial/services (ha (%))	96 (2%)
Classified as marsh/wetland (ha (%))	483 (11%)
Other (ha (%))	190 (4%)
Land values	
Estimated total primary production value ($/year)	$6,900,000
Average land value above 0.9 m AHD ($/ha)	$7,800
Average land value below 0.9 m AHD ($/ha)	$3,500

8.7.1 Site description

Palmers Channel connects Wooloweyah Lagoon to the south and the Clarence River to the north. Wooloweyah Lagoon has high ecological value and it is listed on the "Directory of Important Wetlands in Australia", supporting large areas of seagrasses, mangroves and saltmarsh (White, 2009b).

An extensive network of artificial drains and floodgates (shown in Figure 8-30 and Figure 8-31) have been constructed to facilitate development in the Palmers Channel and Taloumbi areas. While drainage works date back to the early 1900's, the majority of major infrastructure was first constructed in 1966 by Clarence River County Council (Foley and White, 2007).

Major drainage works include the Taloumbi Ring Drain and five (5) radial drains that allow agricultural uses of the low area along the banks of Wooloweyah Lagoon. Due to the location in the lower estuary, floodgates are used in the areas to prevent saline intrusion into the drainage system. Drainage works also included a small levee that was built in 1967 to provide protection in the Palmers Channel area against small flood events.

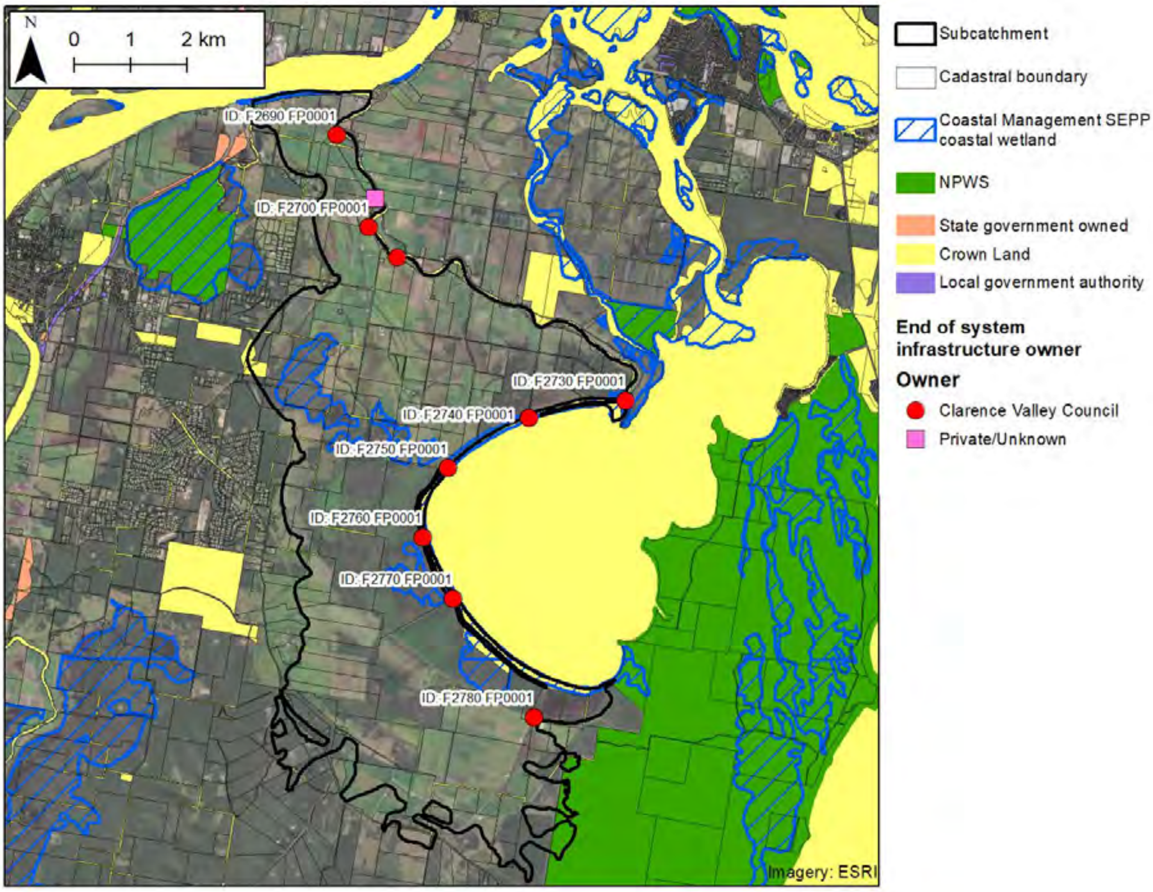

Figure 8-30: Taloumbi/Palmers Channel subcatchment land and end of system infrastructure tenure

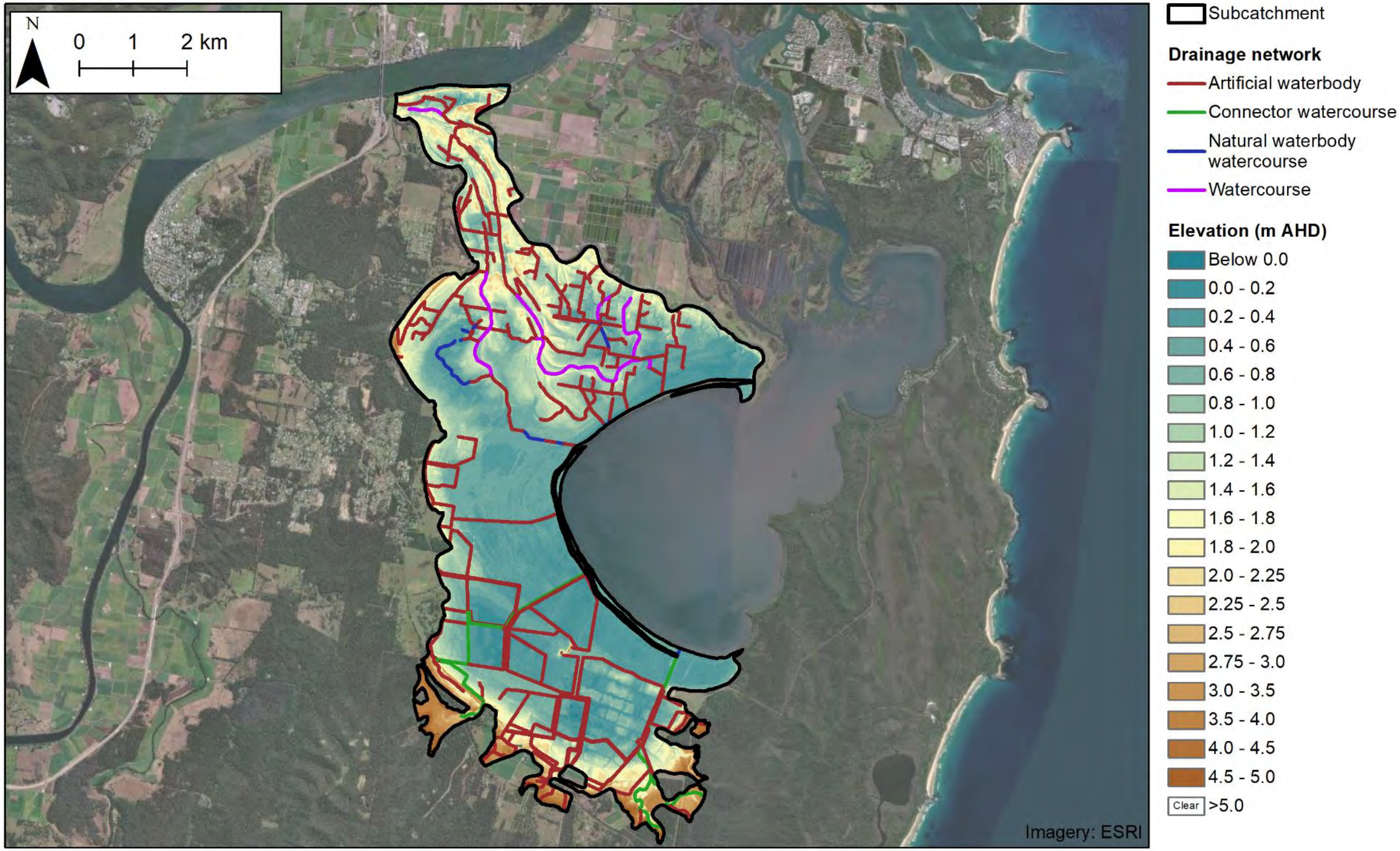

Figure 8-31: Taloumbi/Palmers Channel subcatchment elevation and drainage network

8.7.2 History of remediation

Palmers Channel was used as a demonstration site in the Clarence River for modifying floodgates to allow controlled tidal flushing in 2001 and 2002 (Davison and Wilson, 2003). The results of this trial showed that landholders preferred modifications with auto-tidal buoyancy gates (that do not require active management) with a horizontal gantry that allows the floodgate to be fully winched open as desired. As a result, all of the CVC floodgates along Palmers Channel are fitted with both a buoyancy controlled auto-tidal floodgate and winch mechanism. This subcatchment is shown in Figure 8-32, and includes floodgate ID F-2690-FT-0001, F-2700-FT-0001 and F-2730-FT-0001.

CVC data suggests that there are water control structures on floodgate ID F-2750-FB-0001 on the radial drain that connects to Little Reedy Creek and floodgate ID F-2740-FB-0001. In general, water control structures in the CVC dataset identifies a weir structure that is designed to hold back water on the floodplain. Neither of these structures were inspected during WRL field investigations and the geometry of the structures is unknown. However, aerial imagery suggests both of the water control structures were installed between 2009 and 2011, and likely based on the recommendations of Foley and White (2007). The structure near Little Reedy Creek was recommended to raise the water table in Little Reedy Creek to improve ecological outcomes and reduce ASS drainage. The second water control structure is upstream of the location recommended by Foley and White (2007) (initially recommended to prevent saline intrusion into Reedy Creek), however would still be effective in excluding saline waters from the local drainage system.

As well as the modifications of floodgates and installation of water control structures (most likely weirs), there has also been active remediation of a 50 ha area of saltmarsh in the east Taloumbi area, highlighted in Figure 8-32. This involved moving the Taloumbi Ring Drain (and associated levee) landward by 700 m to open the 50 ha area (elevation of approximately 0 m AHD) to regular tidal inundation. Inundation of this area is now estimated to occur approximately 264 days per year (compared to 1.6 days a year prior to remediation), promoting the establishment of intertidal wetland habitat (Wetland Care Australia, 2002).

Sugar cane farms in the Clarence River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Taloumbi/Palmers Channel subcatchment were not obtained, cane farms typically implement the following ASS management actions:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

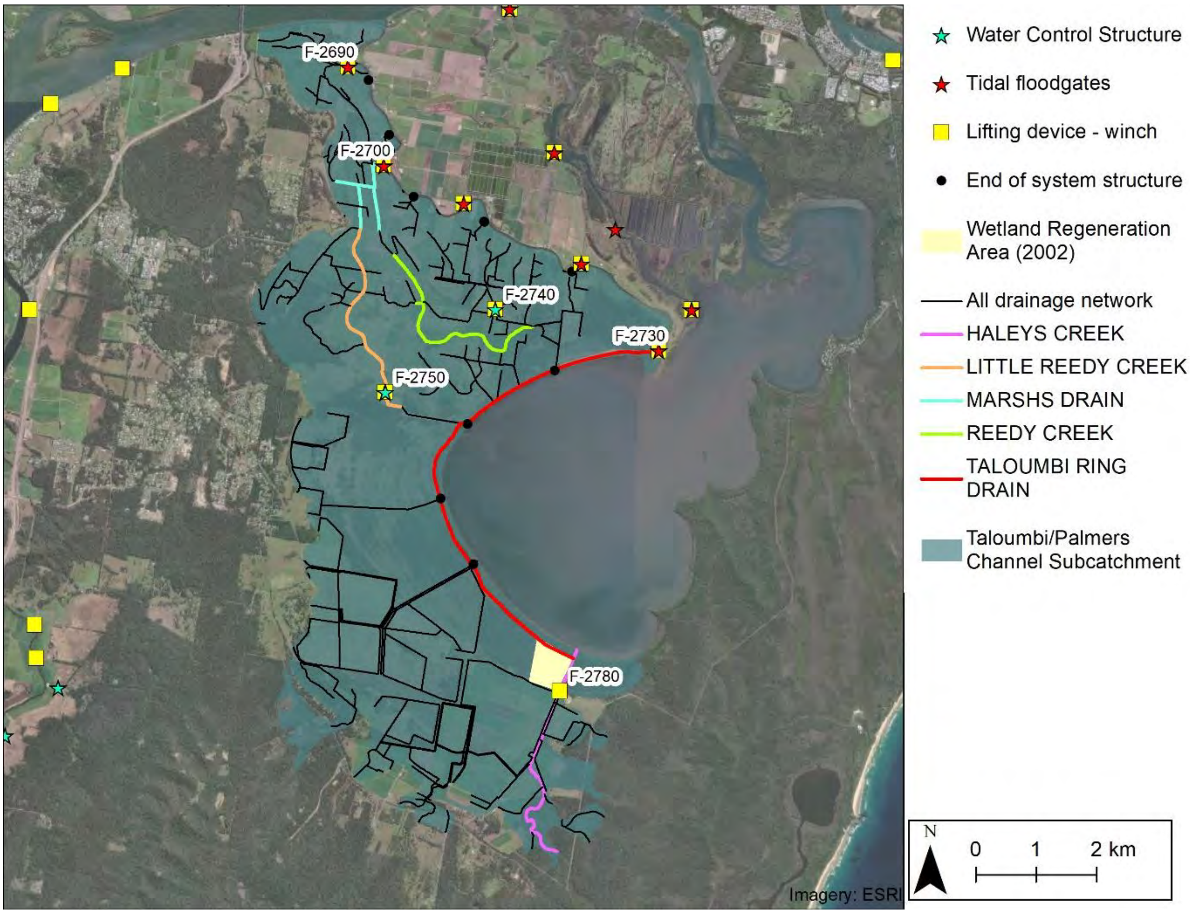

Figure 8-32: Taloumbi/Palmers Channel subcatchment including previous remediation actions

8.7.3 Prioritisation of management areas in Taloumbi/Palmers Channel subcatchment

The Taloumbi/Palmers Channel subcatchment is ranked fourth subcatchment in the Clarence River floodplain with regards to acid generation, and ranked fourth for blackwater generation. The subcatchment has been further divided into four (4) management areas (referred to as PCT1 – PCT4) to provide additional information on the potential sources of acid and blackwater in the Taloumbi/Palmers Channel subcatchment. The areas have been delineated based on data availability, elevation, changes in soil acidity and drainage units.

The management areas have been prioritised for acid generation using the method described in Section 4.2. The results of the acid prioritisation are shown in Figure 8-33 and summarised in Table 8-10. The highest priority management area is PCT1, in Taloumbi, primarily due to having larger catchment and therefore more potential for acid to be mobilised and transported to downstream waterways. There were no soil profiles available in management area PCT3, so the prioritisation could not be completed in this subcatchment. However, Table 8-10 shows it has a comparable surface water factor to management areas PCT2 and PCT4, so it is assumed to have a low priority.

Figure 8-34 shows the management areas of the Taloumbi/Palmers Channel subcatchment below the median elevation for blackwater generation (+0.9 m AHD). As elevation is a primary driver of the production of blackwater, the areas below this level typically have the greatest contribution to the risk of large scale deoxygenation. The management areas that are likely to be contributing the most to blackwater generation is PCT1.

Based on the prioritisation of management areas for acid generation, and the areas below the median elevation for blackwater generation, it is suggested that management efforts to improve water quality should initially focus on management area PCT1.

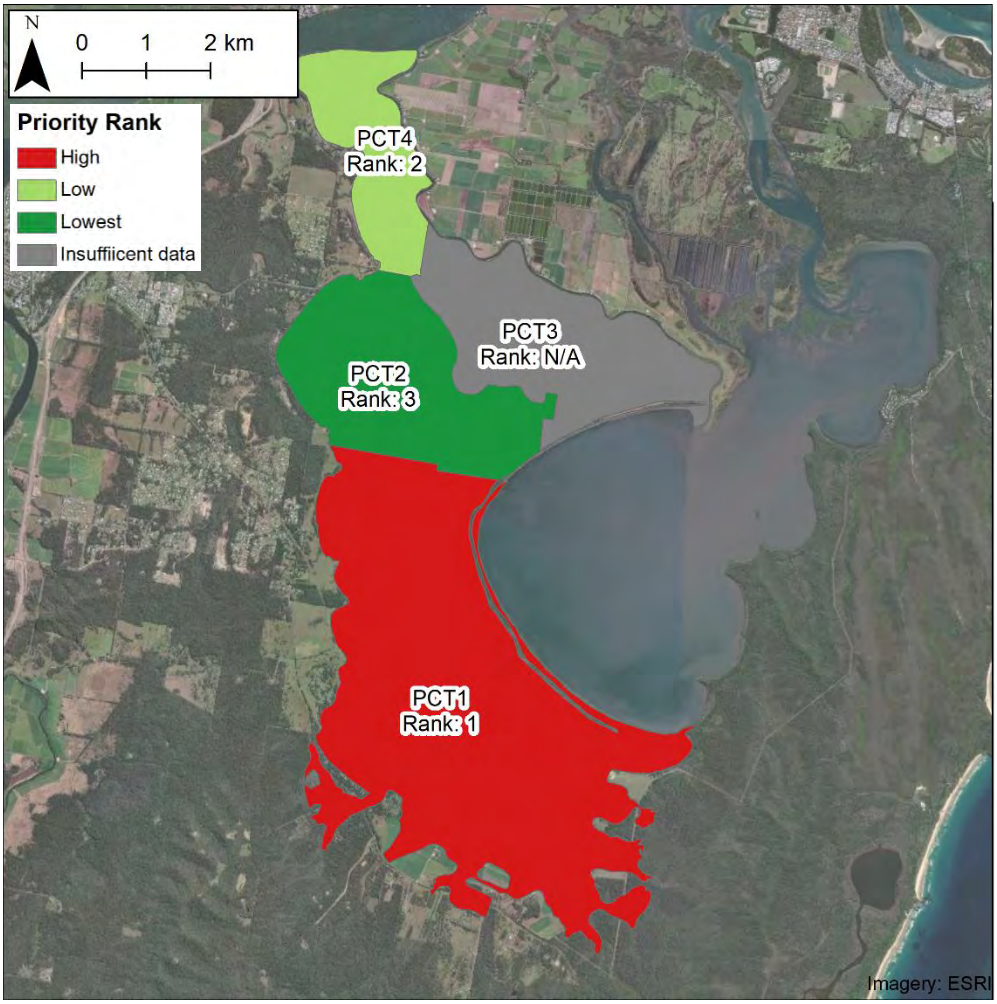

Figure 8-33: Taloumbi/Palmers Channel subcatchment management areas acid prioritisation

Table 8-10: Management area acid prioritisation of Taloumbi/Palmers Channel subcatchment

Management area	Groundwater factor	Surface water factor	Final acid factor	Final rank
PCT1	37	1,243	46,248	1
PCT4	20	129	2,609	2
PCT2	5	228	1,168	3
PCT3	Insufficient data	229	Insufficient data	4

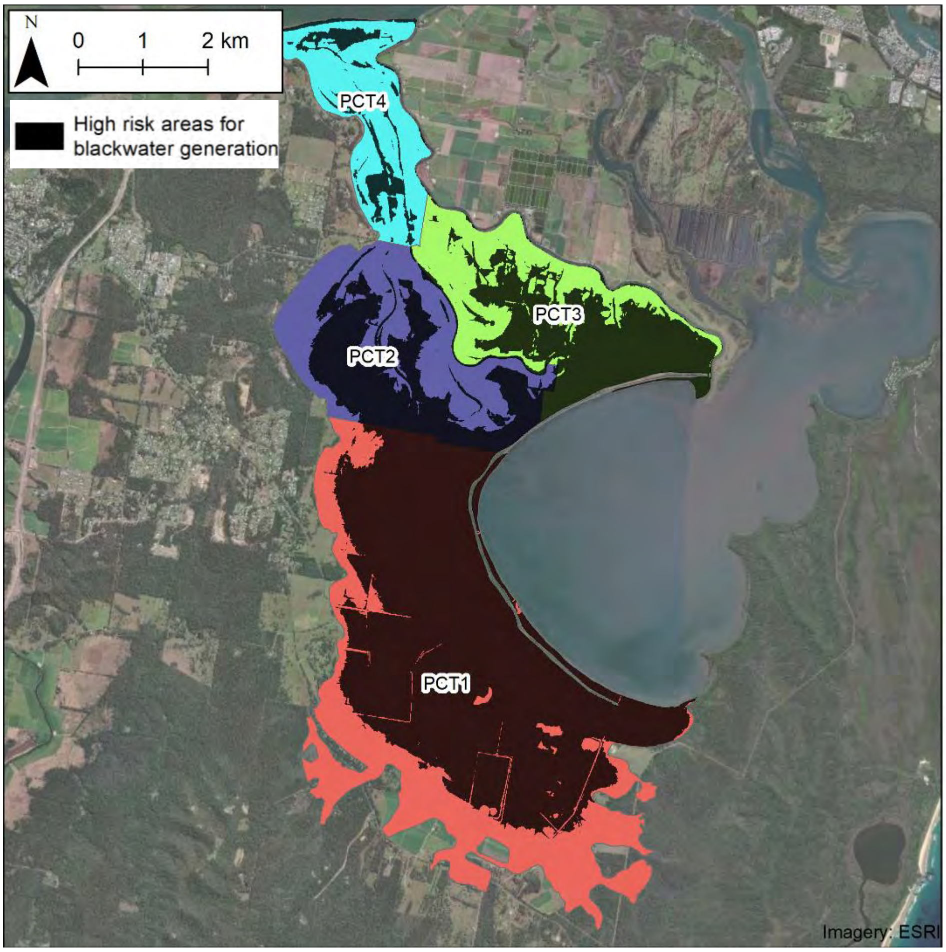

Figure 8-34: High risk areas for blackwater generation in management areas in Taloumbi/Palmers Channel subcatchment (median blackwater level +0.9 m AHD)

8.7.4 Floodplain drainage -sea level rise vulnerability

Figure 8-35 summarises the sea level rise vulnerability in the Palmers Channel/Taloumbi subcatchment. The most vulnerable parts of the subcatchment are in Taloumbi, adjacent to Wooloweyah Lagoon, where there is a substantial area that will have a medium risk in the near future, and high risk in the far future.

All primary floodgates within the subcatchment are classified as ‘Most vulnerable’ in the far future, as shown in Figure 8-36, meaning the 50th percentile water level will be above the obvert of these structures. Additionally, one of the floodgates (ID F-2710-FP-0001) is classified as ‘Most vulnerable’ in the present day analysis. The majority of this subcatchment is likely to be impacted by reduced drainage in the near to far future.

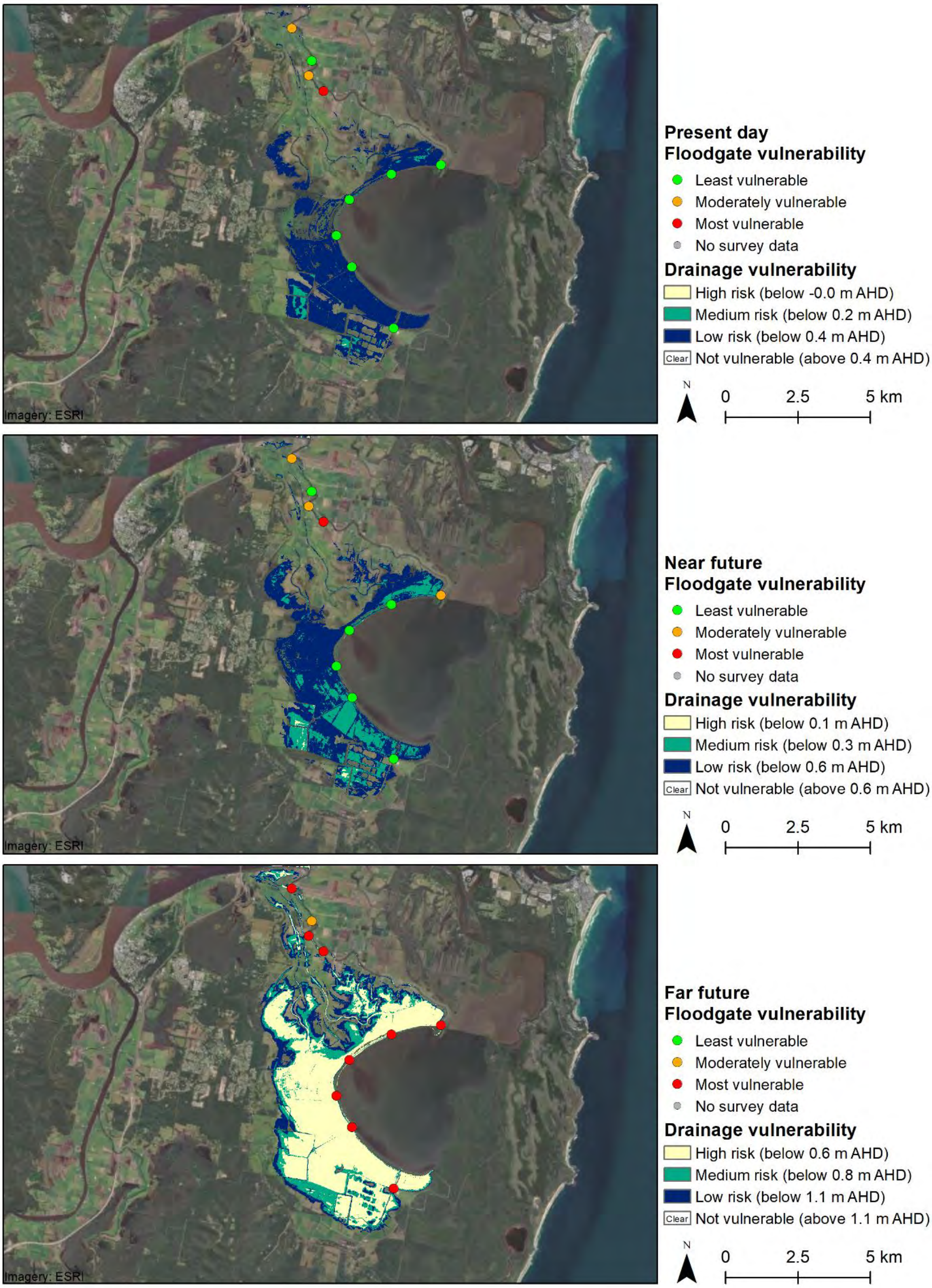

Figure 8-35: Sea level rise drainage vulnerability – Taloumbi/Palmers Channel subcatchment

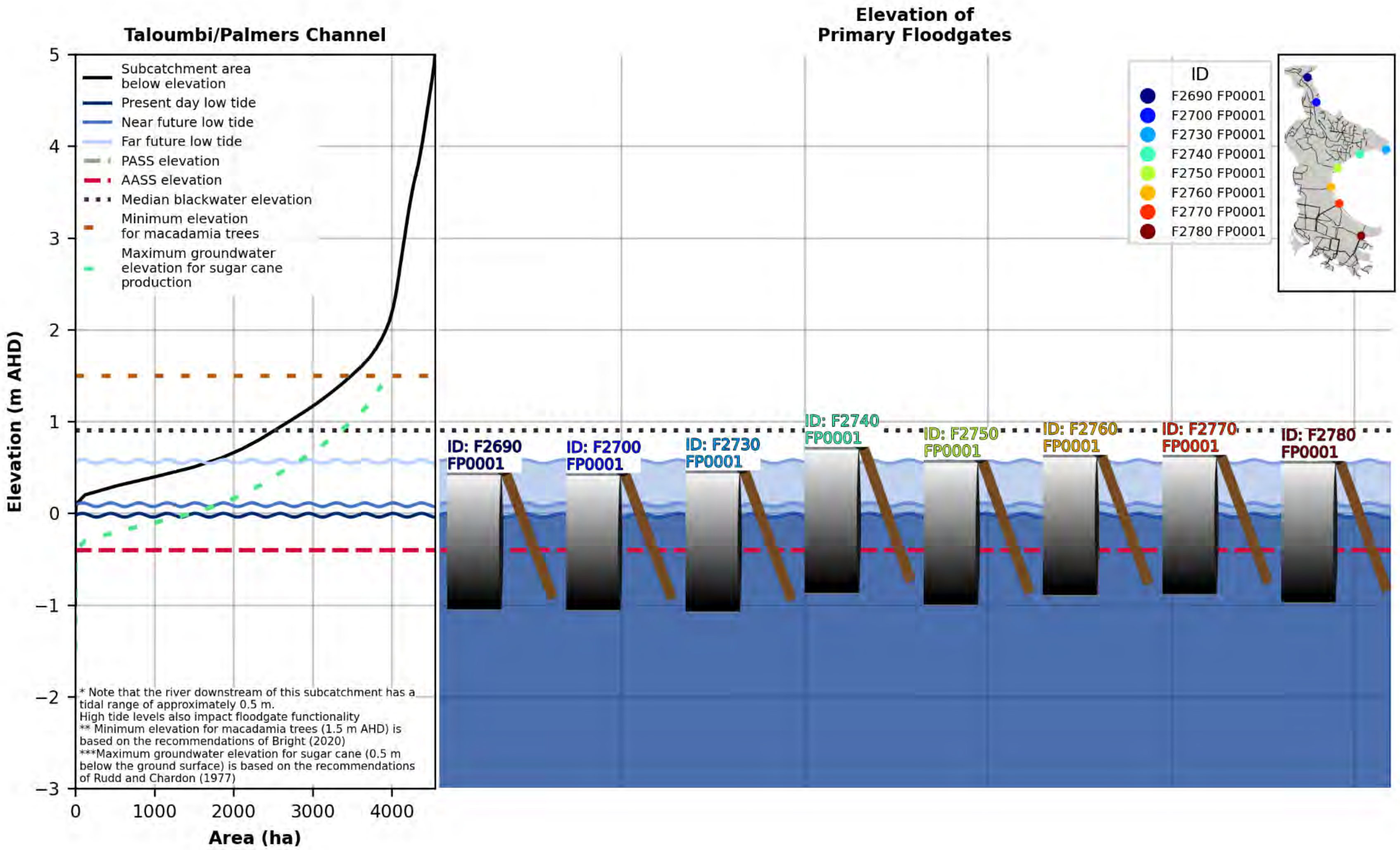

Figure 8-36: Primary floodgates and key floodplain elevations –Taloumbi/Palmers Channel subcatchment

8.7.5 Management options

Short-term management options
In management area PCT1, a small area of saltmarsh was remediated in 2002 (see Figure 8-32) through re-design of the local levee and drainage system. If existing landholders are interested in trials, this approach could be expanded along the Wooloweyah Lagoon shoreline to encourage additional intertidal vegetation and important aquatic habitat. In addition, auto-tidal gates should be considered for the floodgates along Wooloweyah Lagoon to allow flushing and fish passage through the radial drain, as per the recommendations of Foley and White (2007), however, the low elevation of the Taloumbi floodplain limits the magnitude of tidal flushing that can be achieved while maintaining existing land use and productivity. Where possible, drains should be reshaped to reduce the interaction of drainage channels with acidic soil layers.

Where possible, the use of dropboard weirs to encourage wet pasture management on existing grazing land would reduce acid and blackwater drainage from the management area, while allowing post-flood drainage efficiency to be maintained. Any plans for wet pasture management would require the cooperation and input from local landholders to ensure the resulting pasture is appropriate for their stock or needs.

This subcatchment also contains sensitive receivers (see Appendix J), including saltmarsh, mangroves and Coastal Management SEPP coastal wetlands. Management and maintenance of these areas should be supported as they provide important habitat and biodiversity within the Clarence River estuary.

Long-term management options
In management area PCT1 and the eastern half of PCT3, future sea level rise is likely to impact present day drainage. In the far future, low lying areas may become poorly drained and be subject to prolonged inundation, and could be targeted for remediation of the natural estuarine hydrology. This could be achieved through shifting the existing ring drain (and associated levee) landward and allowing inundation of low-lying areas. This would create significant estuarine ecosystems, while also reducing the acid and blackwater risk within the identified management areas.

In higher elevation locations, opportunities for drain infilling or reshaping could be investigated. Reducing drainage and installation of small dropboard weirs on a paddock scale drains would allow for freshwater retention and establishment of wetland habitats. By increasing the time of inundation, carbon processes that occur when organic matter decomposes would be able to be completed, which would substantially reduce the impact of blackwater.

Management area PCT 4 and the western portion of management areas PCT 3 and PCT 4 are generally higher than the rest of the Taloumbi/Palmers Channel subcatchment and contribute less to blackwater and acid generation than other areas (i.e. management area PCT 1). However, reduction of the drainage density in these managements areas would reduce acid drainage potential. Where current land uses are impacted by reduced drainage under future sea level rise, establishment of wetland habitats should be encouraged through the removal of floodgates.

A summary of the recommended management options for the Taloumbi/Palmers Channel subcatchment is provided in Table 8-11.

Table 8-11: Summary of management options for Taloumbi/Palmers Channel subcatchment

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Floodgate modification	Moderate	Small	Negligible
Short-term	Wet pasture management	None	Moderate	Moderate
Long-term	Restoration of natural estuarine hydrology	High	High	High

8.8 Coldstream River subcatchment

Acid priority rank:	**6**
Blackwater priority rank:	**1**
Infrastructure	
Approximate waterway length (km)	196
# Privately owned end of system structures	5
# Publicly owned end of system structures	34
# End of system structures within coastal wetlands	2
# Publicly owned end of system structures within coastal wetlands	2
Primary floodplain infrastructure (ID):	F-1420-FB-0001, F-1430-FB-0001, F-1440-FB-0001, F-1530-FB-0001, F-1570-FB-0001, F-1650-FB-0001, F-1660-FB-0001, F-1680-FB-0001, F-1690-FB-0001, F-1700-FB-0001, F-2030-FB-0001, F-2050-FP-0001, F-4320-FP-0001
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.4 to 1.1
Approximate AASS elevation (m AHD)	0.3
Approximate PASS elevation (m AHD)	-0.3
Median blackwater elevation (m AHD)	1.9
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0.0
Far future low level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	37.4
Saltmarsh (km)	16.7
Seagrass (km)	28.6
Mangroves (km)	0.2
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	13,060
Classified as conservation and minimal use (ha (%))	161 (1%)
Classified as grazing (ha (%))	8,959 (69%)
Classified as forestry (ha (%))	61 (0%)
Classified as sugar cane (ha (%))	253 (2%)
Classified as horticulture (ha (%))	11 (0%)
Classified as other cropping (ha (%))	255 (2%)
Classified as urban/industrial/services (ha (%))	257 (4%)
Classified as marsh/wetland (ha (%))	2,541 (19%)
Other (ha (%))	563 (4%)
Land values	
Estimated total primary production value ($/year)	$3,700,000
Average land value above 1.9 m AHD ($/ha)	$7,300
Average land value below 1.9 m AHD ($/ha)	$2,500

8.8.1 Site description

The Coldstream River is a major tributary of the Clarence River, with an upstream catchment of approximately 285 km^2. At least 37 end-of-system floodgates service the Coldstream River subcatchment, shown in Figure 8-37, and approximately 200 km of drains and watercourses have been mapped in the subcatchment. The subcatchment topography is a complicated series of deltas that have created a series of large, low backswamp areas which have been heavily modified and drained to facilitate agricultural land uses (Figure 8-38). The majority of the subcatchment (69%) is used for grazing.

Low oxygen blackwater has been observed in the Coldstream River, usually associated with summer rainfall (Manly Hydraulics Laboratory, 1995; Roads and Maritime Services, 2016). Fish kills in the Coldstream River have been recorded in the DPI fish kill database at least three (3) times (NSW DPI, 2020). The Coldstream River was identified as a key source of blackwater in the Clarence River floodplain by Walsh et al. (2004).

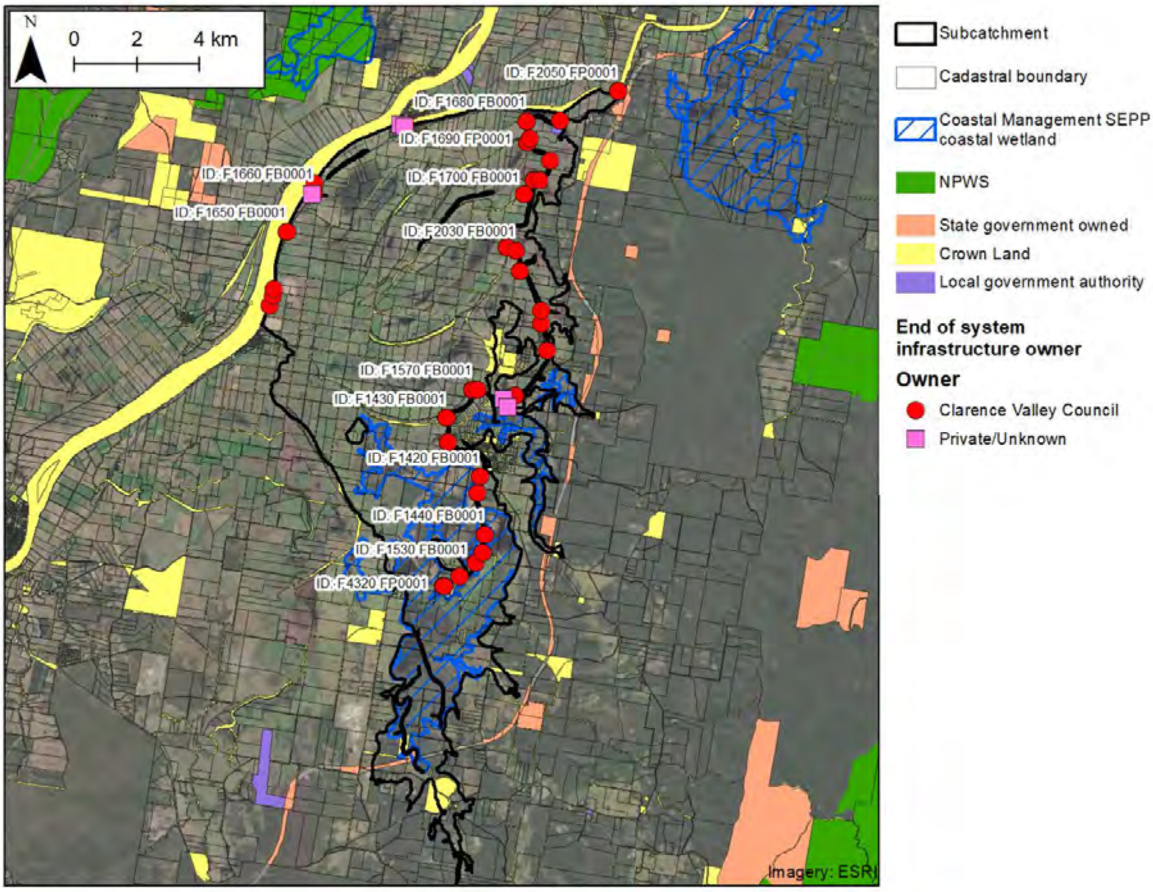

Figure 8-37: Coldstream River subcatchment land and end of system infrastructure tenure

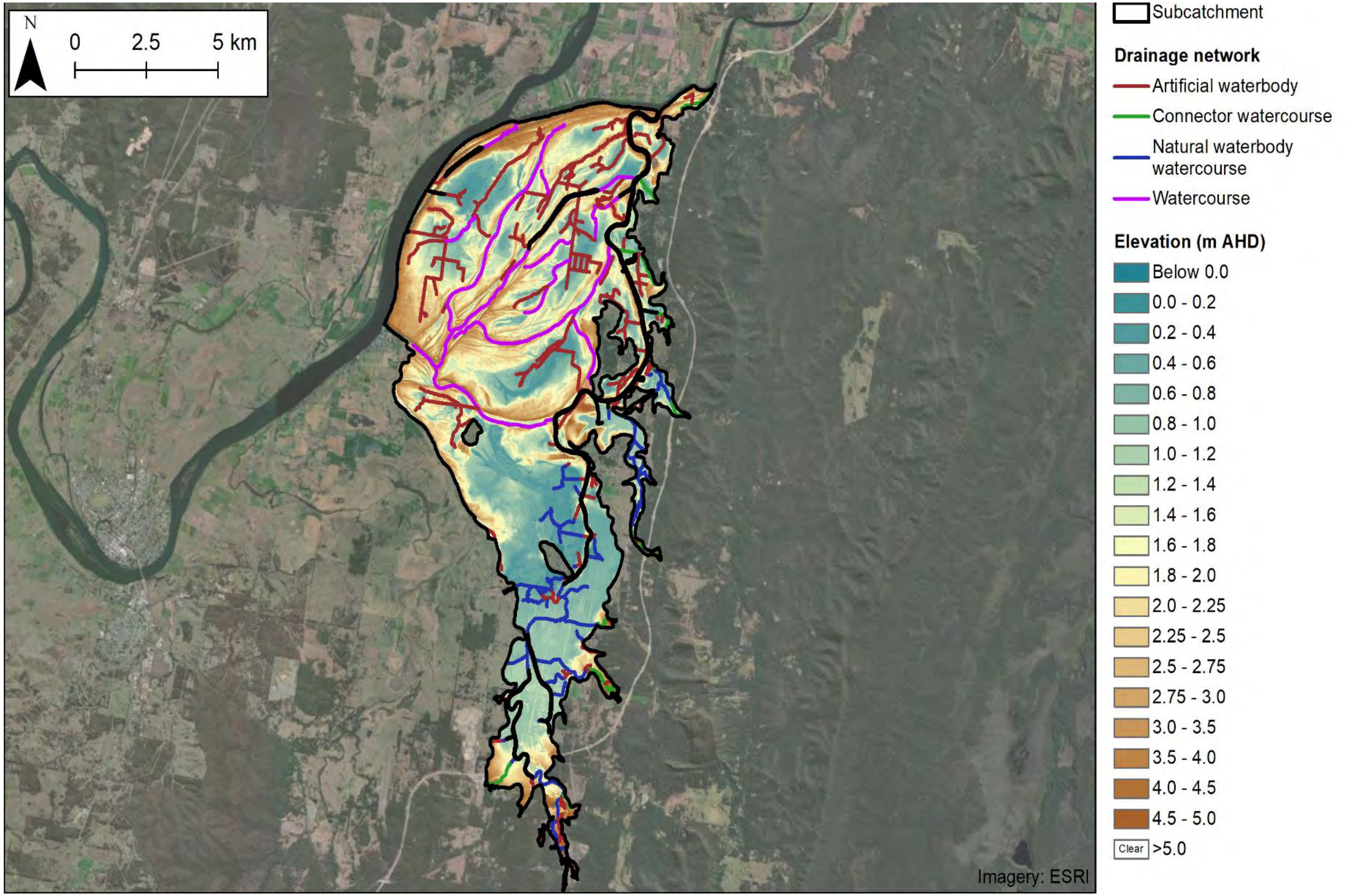

Figure 8-38: Coldstream River subcatchment elevation and drainage network

8.8.2 History of remediation

A large number of floodgates have been modified throughout the Coldstream River subcatchment, highlighted in Figure 8-39. Information related to floodgate modifications is mainly based on spatial information provided by CVC, and was further updated in locations where data collection was completed for this study. Modifications include:

- Floodgates fitted with a lifting device (winch or similar) on at least 15 floodgates. The management regime of the winches is unknown;
- Auto-tidal buoyancy gates on at least seven (7) floodgates, mostly in the lower Coldstream River; and
- A sluice gate fitted on floodgate ID F-1680-FS-0001 on Dennys Gully.

As well as modifications to existing floodgates, the CVC data indicated that at least five (5) water control structures have been installed in the Coldstream River subcatchment. In general, water control structures in the CVC dataset identify a weir structure that is designed to hold back water on the floodplain. These structures include:

- Floodgate ID F-2020-FH-0001 – on the right bank of the lower Clarence River. This structure was not inspected as a part of this study and Council records do not include the type of structure. It may be a weir that retains water on small backswamp upstream of the drain;
- Floodgate ID F-1600-FH-0002 – which is part of the Bleechmores Drain management (which also includes an auto-tidal floodgate and winch on the downstream floodgate). Council records show that this structure is a ‘head and discharge’ structure, which effectively acts as a removeable weir. Photographs in OceanWatch (n.d.) show that the drainage management allowed for wet pasture management to be undertaken;
- Floodgate ID F-1420-FH-0001 – Council records show that this structure is a ‘head and discharge’ structure, which effectively acts as a removeable weir. This holds back water on the low backswamp area that was historically a 2.5 km^2 wetland (Williams, 2000). This is upstream of another floodgate that can be winched open;
- Floodgate ID F-1440-FP-0001 – Council records suggest that there is a water control structure on the Kenny-Lloyds Drain. It is assumed that this is in the form of a dropboard weir or similar as per the recommendations of Williams (2000) that allows the land holders to control ponding of freshwater;
- Floodgate ID F-1530-FP-0002 – Council records suggest that there is a water control structure on the Kinghorns Drain. It is assumed that this is in the form of a dropboard weir or similar, coupled with managed opening of the downstream floodgate as per the recommendations of Williams (2000).

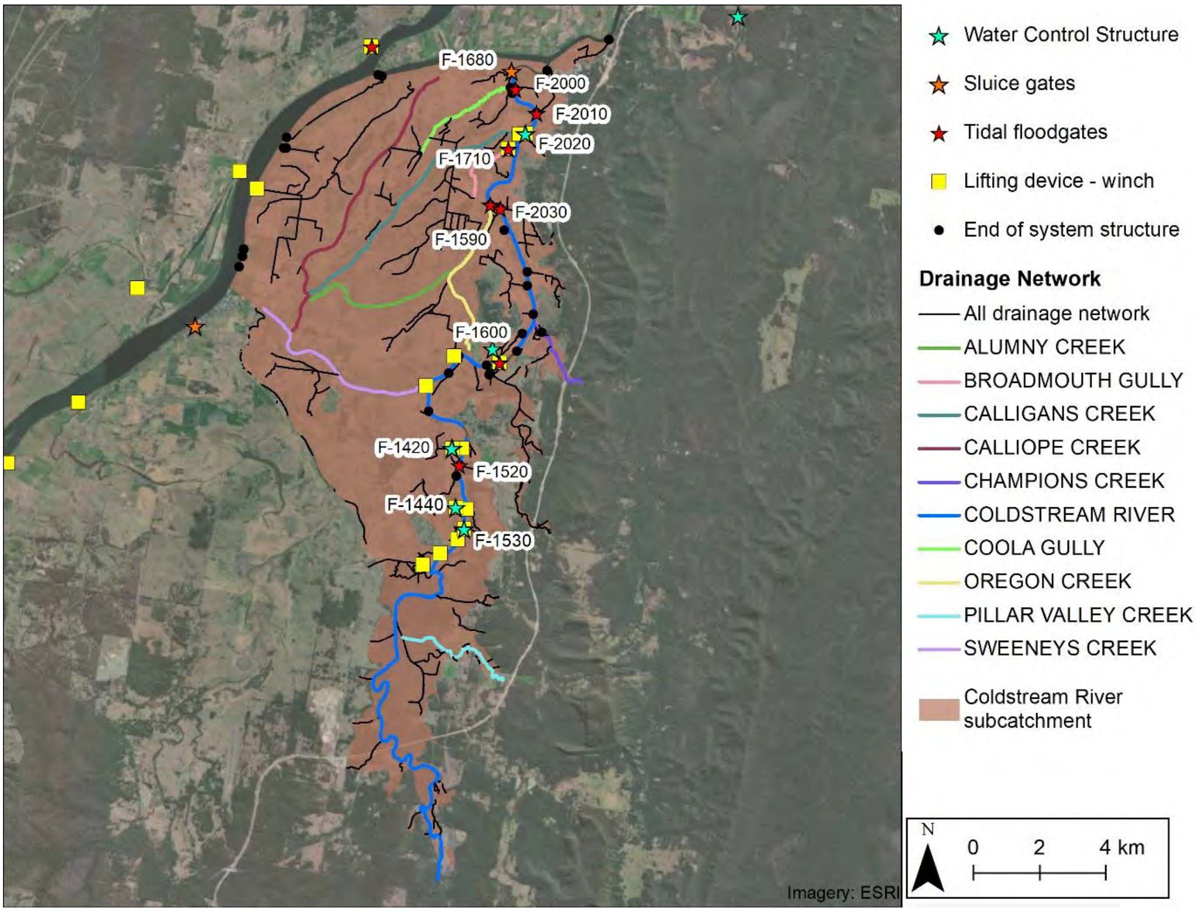

Figure 8-39: Coldstream River subcatchment including previous remediation actions (note that floodgates with lifting devices are not labelled with an ID number)

8.8.3 Prioritisation of management areas in Coldstream River subcatchment

The Coldstream River subcatchment is ranked first in the Clarence River floodplain with regards to blackwater generation, and ranked fifth for acid generation potential. The subcatchment has been further divided into five (5) management areas (referred to as CR1 to CR5) to provide additional information on the sources of acid and blackwater in the Coldstream River subcatchment. The areas have been delineated based on data availability, elevation, changes in soil acidity and drainage units.

Figure 8-40 shows the management areas of the Coldstream River subcatchment below the median elevation for blackwater generation (+1.9 m AHD). As elevation is a primary driver of the production of blackwater, the areas below this level typically have the greatest contribution to the risk of large scale deoxygenation. The management area that is likely to be contributing the most to blackwater generation is CR1, although blackwater is generated from across the whole subcatchment.

The management areas have been prioritised for acid generation using the method described in Section 4.2. The results of the acid prioritisation are shown in Figure 8-41 and summarised in Table 8-12. The highest priority management area is CR1, primarily due to more acidic soils and a higher soil hydraulic conductivity.

Based on the prioritisation of management areas for acid generation, and the areas below the median elevation for blackwater generation, it is suggested that management efforts to improve water quality should initially focus on management area CR1, although reductions in acid and blackwater drainage in every subcatchment could result in significant improvements in water quality.

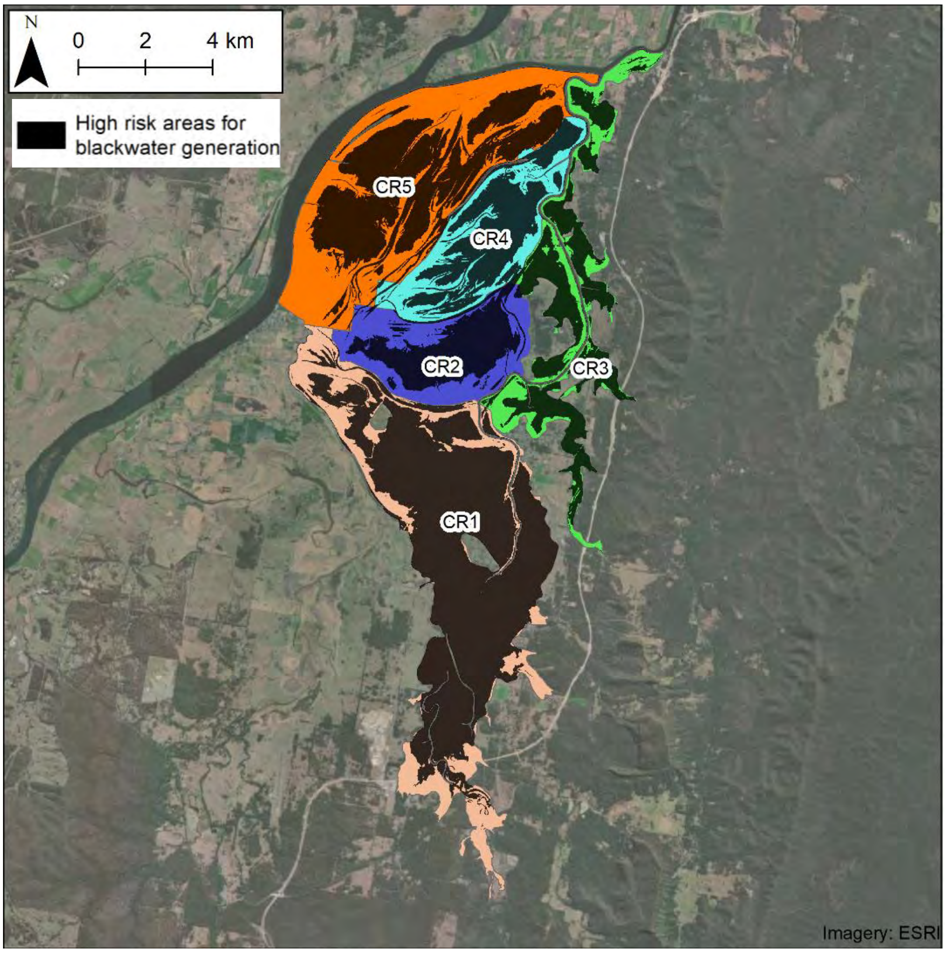

Figure 8-40: High risk areas for blackwater generation in management areas in Coldstream River subcatchment (median blackwater level +1.9 m AHD)

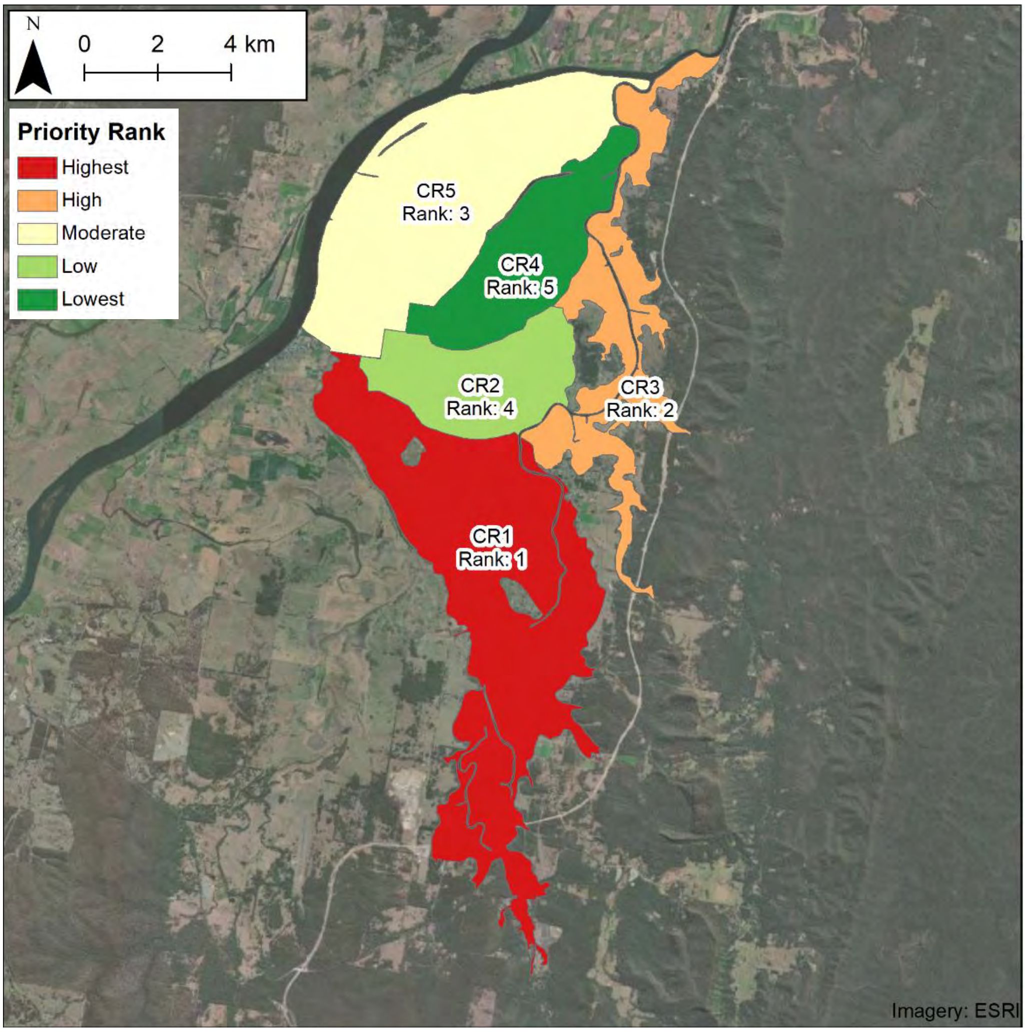

Figure 8-41: Coldstream River subcatchment management areas acid prioritisation

Table 8-12: Management area acid prioritisation of Coldstream River subcatchment

Management Area	Groundwater Factor	Surface Water Factor	Final Acid Factor	Final Rank
CR1	123	342	41,963	1
CR3	16	754	12,095	2
CR5	13	260	3,408	3
CR2	13	69	871	4
CR4	1	268	166	5

8.8.4 Floodplain drainage - sea level rise vulnerability

Figure 8-42 summarises the sea level rise vulnerability throughout the Coldstream River subcatchment. Under present day conditions, there are already areas throughout the subcatchment that are classified as low risk in the Coldstream River, which may already be affected by reduced drainage (below +0.6 m AHD). While this area increases under the near future sea level rise scenario, the impact of the far future sea level rise scenario is substantially more significant. Under the far future sea level rise scenario, approximately 2,700 ha is classified as medium risk, representing more than 20% of the Coldstream River subcatchment. Land uses in lower areas of the subcatchment (particularly below 0.8 m AHD) may be affected by sea level rise in the near to far future due to reduced drainage and prolonged inundation.

Two (2) floodgates, including one of the primary floodgates have been identified as “Most vulnerable” under the near future sea level rise scenario (floodgate ID F-1530-FB-0001 and F-1450-FB-0001), both in the upper Coldstream River. The number of “Most vulnerable” floodgates increases to twelve (12) under the far future sea level rise scenario. The elevation of the primary floodgates compared to key elevations is summarised in Figure 8-43.

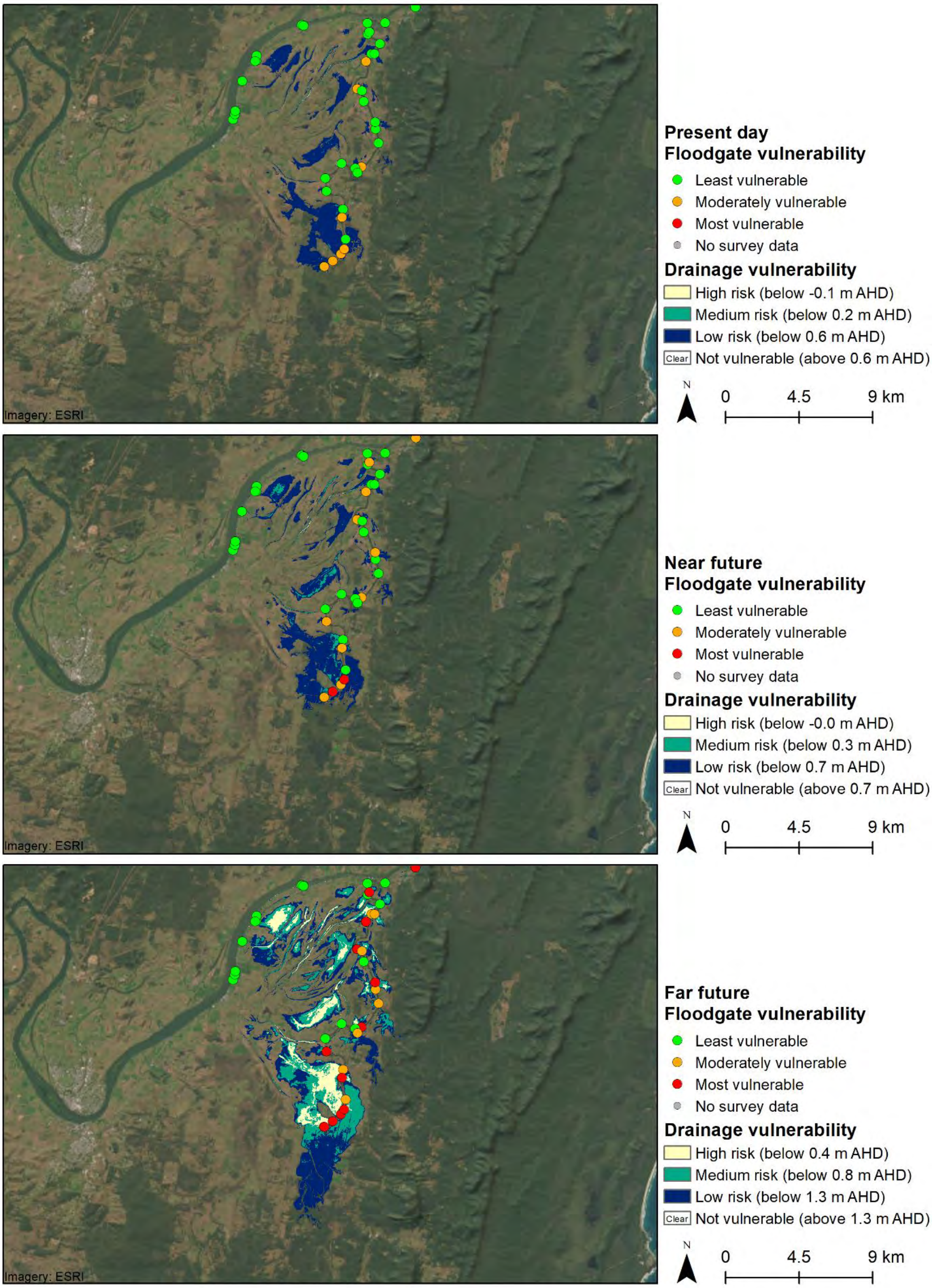

Figure 8-42: Sea level rise drainage vulnerability – Coldstream River subcatchment

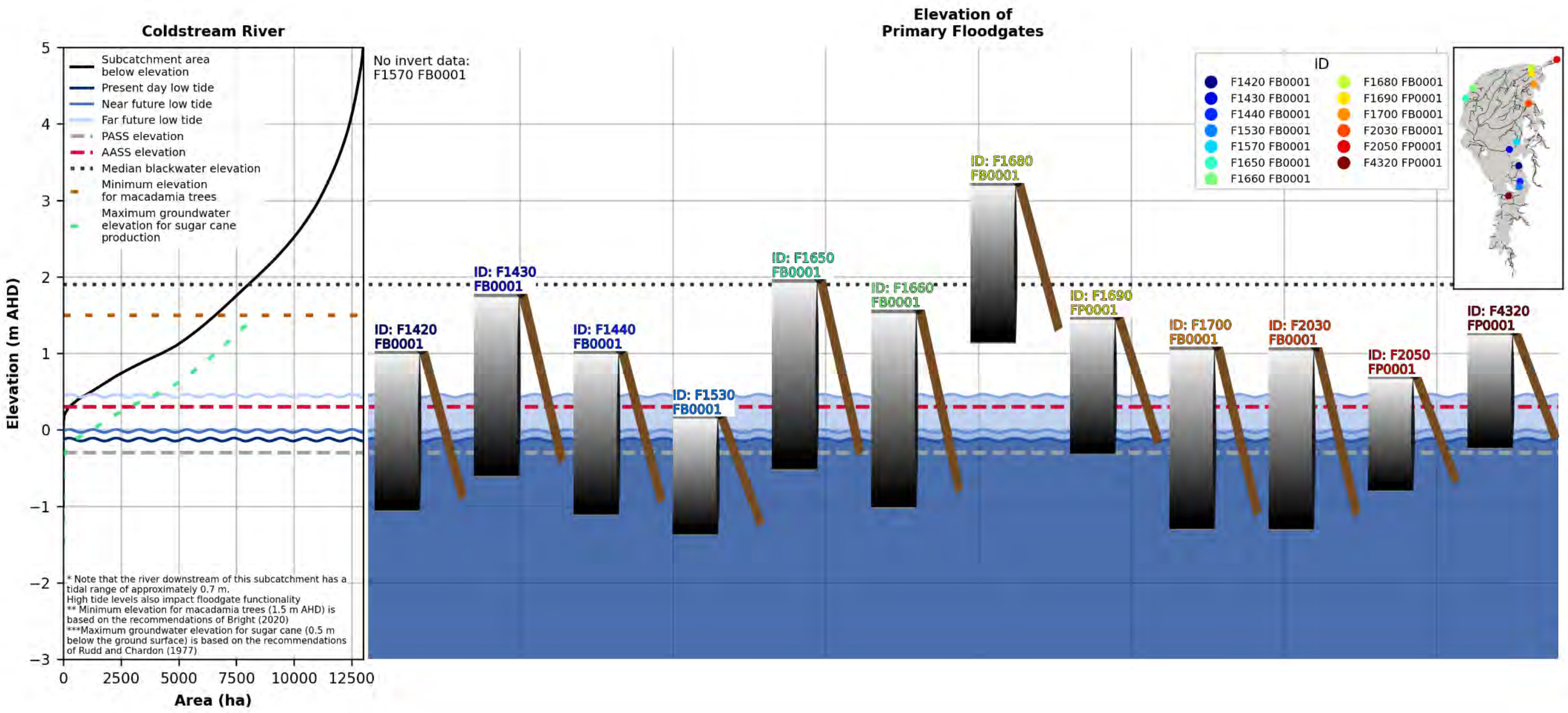

Figure 8-43: Primary floodgates and key floodplain elevations – Coldstream River subcatchment

8.8.5 Management options

Short-term management options

Management area CR1 was identified as the highest risk of ASS drainage and as a significant area for potential blackwater generation. CVC has previously installed lifting devices on most of the floodgates that service this area, and have installed water control structures on at least four (4) drains that retain water on low-lying backswamp areas. It is recommended that the management of existing floodgate lifting infrastructure and water control structures be reviewed to ensure the present management optimises flushing, water retention and wet pasture management in management area CR1. It is also suggested that installation of additional dropboard weirs (or similar water retention structures) be considered on other drains in this area to encourage wet pasture management and reduce acid and blackwater discharges.

As shown in Figure 8-40, all of the management areas in the Coldstream River are likely to be contributing to the generation and discharge of blackwater. Where possible, strategies that reduce the risk of blackwater generation by promoting water tolerant vegetation, such as water retention structures and wet pasture management, should be encouraged throughout the subcatchment. Further investigation may be required to identify the highest priority drain within the subcatchment. Consultation and collaboration with landholders is essential to identify areas that could be managed with additional structures without adversely impacting their present day land use and productivity.

Long-term management options

Reduced drainage due to future sea level rise may impact present day land uses in the Coldstream River subcatchment. Management area CR1 is amongst the lowest areas in the subcatchment and could be considered for restoration of natural freshwater hydrology to limit acid drainage and blackwater runoff from this area. This may include:

- Working with local landholders to investigate economically and socially feasible ways to facillitate changes in land use;
- Infilling artificial drainage networks and restoring natural levees. This will encourage prolonged inundation of the low-lying areas and retain floodwaters after large rainfall events. By restoring the historically (limited) connectivity of backswamp areas with the Coldstream River, the impact of blackwater runoff from this area will be reduced; and
- Additional levees may need to be constructed to manage impacts to surrounding landholders.

Localised restoration of natural freshwater hydrology in other management areas should also be considered where reduced drainage influences future land productivity. Where possible, the low backswamp areas should be restored to freshwater wetland areas by reducing drainage density and restoring natural flow paths and connectivity. Increasing the inundation time over the lowest lying areas of this subcatchment would allow carbon processes that occur when organic matter decomposes to complete, reducing the impact of blackwater in downstream waterways. Note that any changes in hydrology will require additional investigation into the potential impacts to flooding and land uses, and should only be implemented with extensive consultation of local landholders and consideration of the social and economic impacts of such changes.

Due to the size of the Coldstream River, it is also recommended that staged floodwater release from management areas CR2, CR3 and CR4 be investigated to minimise the risk of overwhelming the Coldstream River with blackwater. While the details of a staged released system would require additional investigation, it may include the use of adjustable weirs to manage release times and infilling drains that interconnect backswamps.

A summary of the recommended management options for the Coldstream River subcatchment is provided in Table 8-13.

Table 8-13: Summary of management options for Coldstream River subcatchment

Timeframe	Strategy	Effectiveness at improving: Wetland habitat and fish passage	Effectiveness at improving: Impacts of ASS	Effectiveness at improving: Impacts of blackwater
Short-term	Active floodgate management	Moderate	Small	Negligible
Short-term	Wet pasture management	None	Moderate	Moderate
Long-term	Restoration of natural freshwater hydrology	Moderate	Very High	Very High

8.9 Mororo/Ashby subcatchment

Acid priority rank:	**7**
Blackwater priority rank:	**15**
<u>Infrastructure</u>	
Approximate waterway length (km)	36
# Privately owned end of system structures	8
# Publicly owned end of system structures	11
# End of system structures within coastal wetlands	1
# Publicly owned end of system structures within coastal wetlands	1
Primary floodplain infrastructure (ID):	F-2560-FB, F-2590-FB
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD):	-1.3 to -1
Approximate AASS elevation (m AHD)	1
Approximate PASS elevation (m AHD)	Insufficient information
Median blackwater elevation (m AHD)	0.9
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0.0
Far future low level (m AHD)	0.5
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	14.0
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
<u>Land use</u>	
Total floodplain area (ha)	1,561
Classified as conservation and minimal use (ha (%))	362 (23%)
Classified as grazing (ha (%))	367 (24%)
Classified as forestry (ha (%))	57 (4%)
Classified as sugar cane (ha (%))	579 (37%)
Classified as horticulture (ha (%))	1 (0%)
Classified as other cropping (ha (%))	1 (0%)
Classified as urban/industrial/services (ha (%))	64 (4%)
Classified as marsh/wetland (ha (%))	61 (4%)
Other (ha (%))	71 (5%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$1,800,00
Average land value above 0.9 m AHD ($/ha)	$6,100
Average land value below 0.9 m AHD ($/ha)	$9,100

8.9.1 Site description

The Mororo/Ashby subcatchment is on the left bank of the North Arm of the Clarence River, north-west of Warregah Island. The Mororo Creek Nature Reserve is within the subcatchment (shown in green in Figure 8-44). The primary agricultural land use is sugar cane, although there is also grazing in low areas in the south-west of the subcatchment. The majority of the subcatchment is at, or above, 1 m AHD, although there are localised low areas, as shown in Figure 8-45.

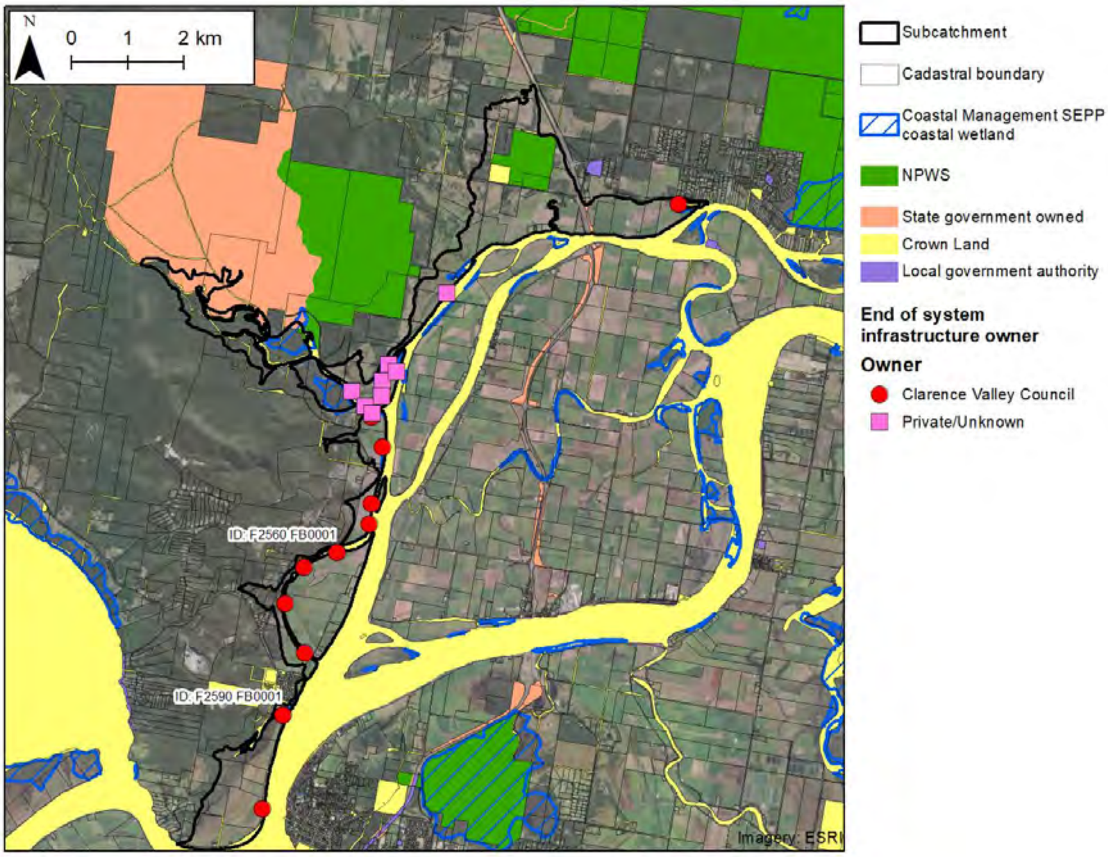

Figure 8-44: Mororo/Ashby subcatchment land and end of system infrastructure tenure

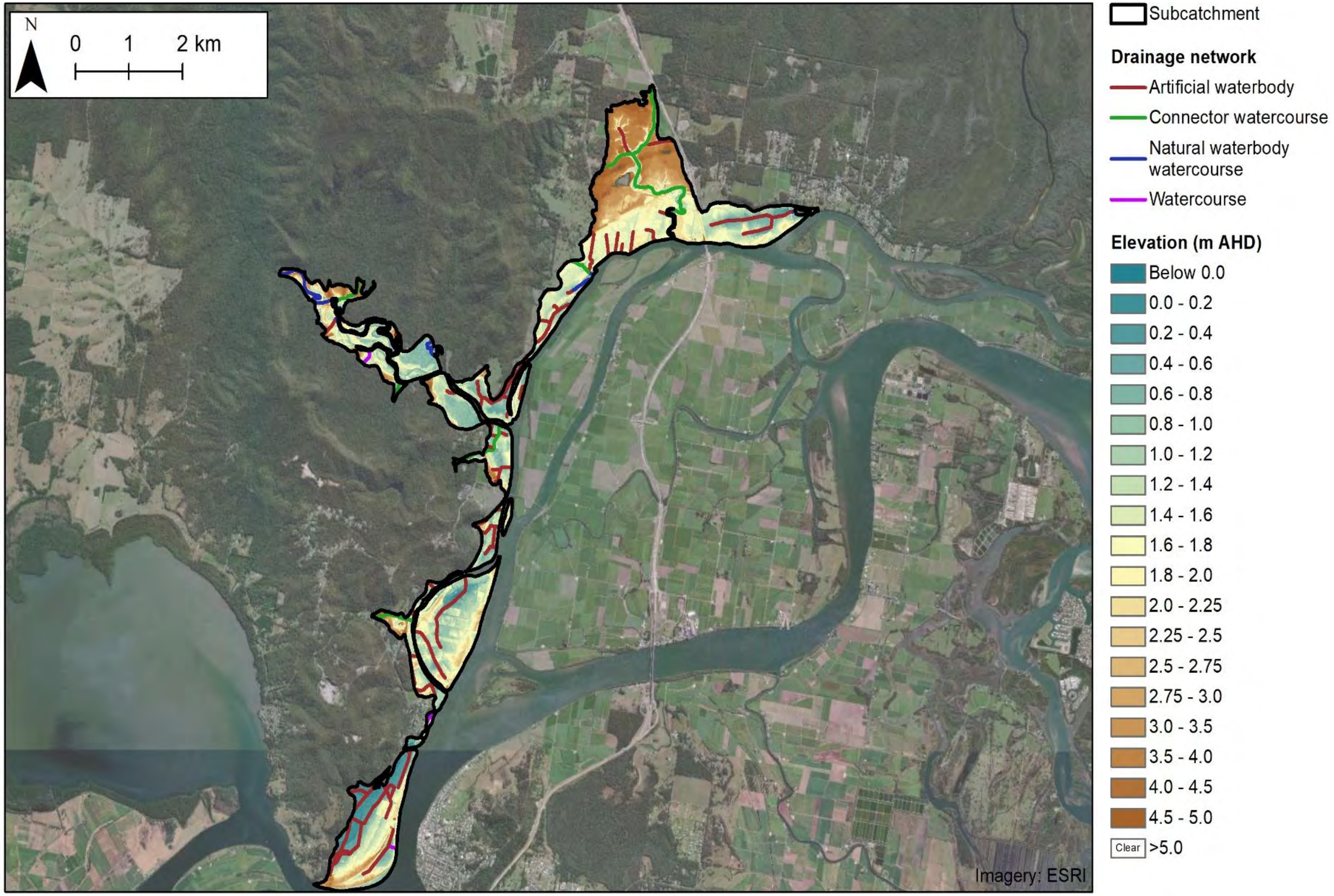

Figure 8-45: Mororo/Ashby subcatchment elevation and drainage network

8.9.2 History of remediation

CVC has previously modified at least six (6) floodgates in the Mororo/Ashby subcatchment to enable controlled tidal flushing, highlighted in Figure 8-46. Based on data provided by CVC and WRL's field investigation, floodgate modifications include:

- Auto-tidal buoyancy gates coupled with a lifting device fitted on to three (3) floodgates (floodgate ID F-2580-FT-0001, F-2560-FB-0001 and F-3080-FT-0001). An example is shown in Figure 8-47;
- Auto-tidal buoyancy gate on floodgate ID F-2620-FT-0001; and
- Lifting devices on floodgate ID F-2550-FP-0001 and F-2600-FP-0001.

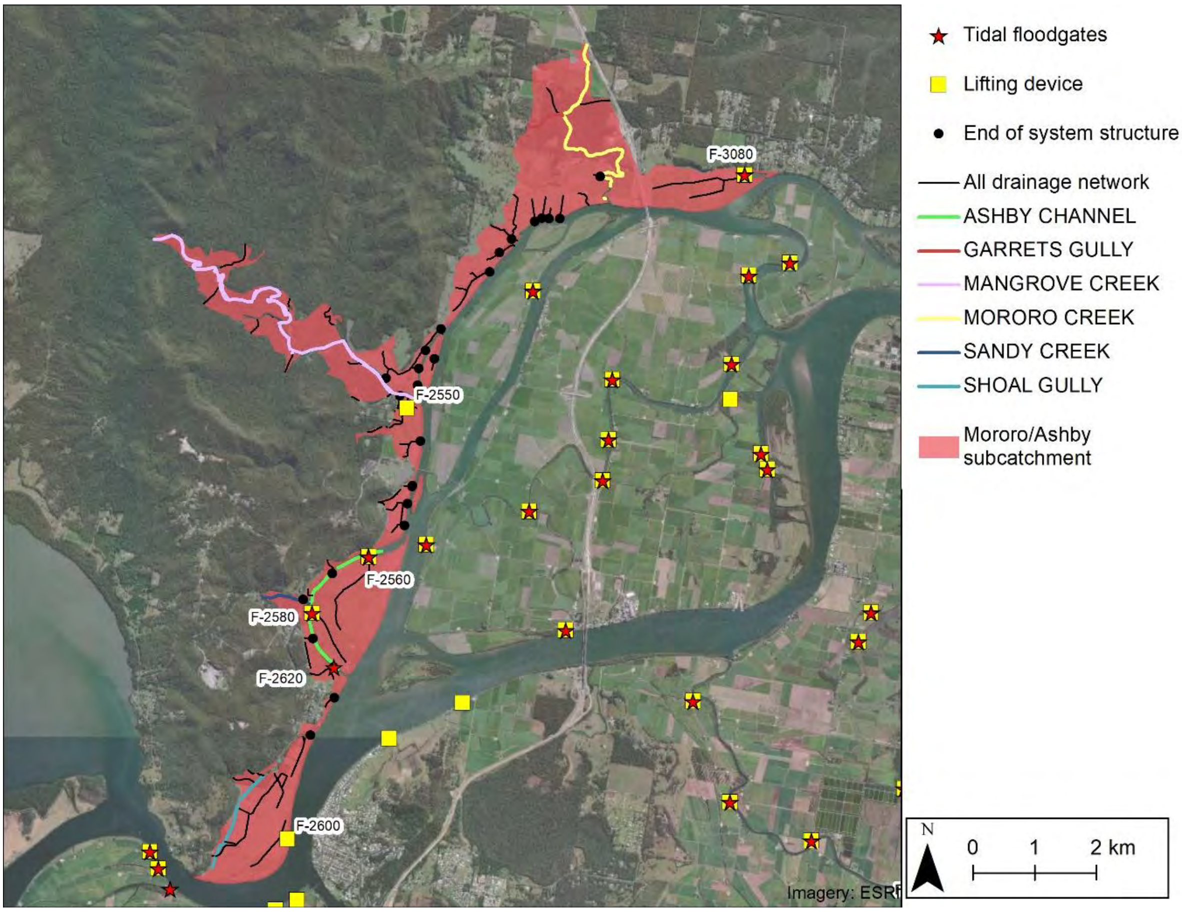

Figure 8-46: Mororo/Ashby subcatchment including previous remediation actions

Sugar cane farms in the Clarence River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Mororo/Ashby subcatchment were not obtained, cane farms typically implement the following ASS management actions:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

Figure 8-47: F-2560-FB-0001 with a buoyancy gate on the middle floodgate, and lifting device on all three floodgates

8.9.3 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability of the Mororo/Ashby subcatchment is shown in Figure 8-48. The majority of the subcatchment is relatively high, except for the area around Shoal Gully in the south-western tip of the subcatchment. Floodgate infrastructure within this subcatchment will likely be severely affected by sea level rise, with all structures classified as ‘Most vulnerable’ in the far future, and 13 out of 19 structures classified as ‘Moderately vulnerable’ in the near future. This area will likely be impacted by reduced drainage in the near and far future.

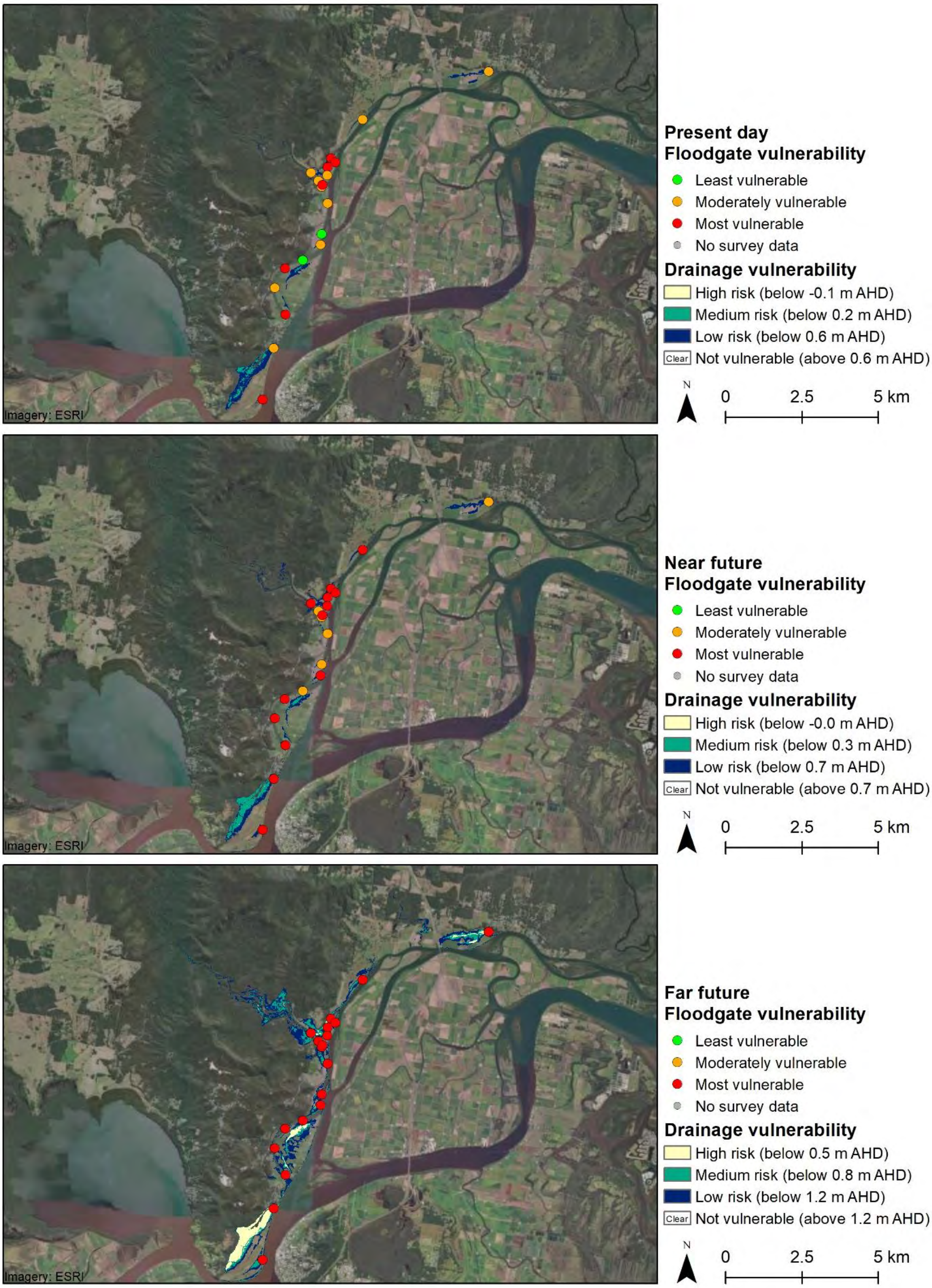

Figure 8-48: Sea level rise drainage vulnerability – Mororo/Ashby subcatchment

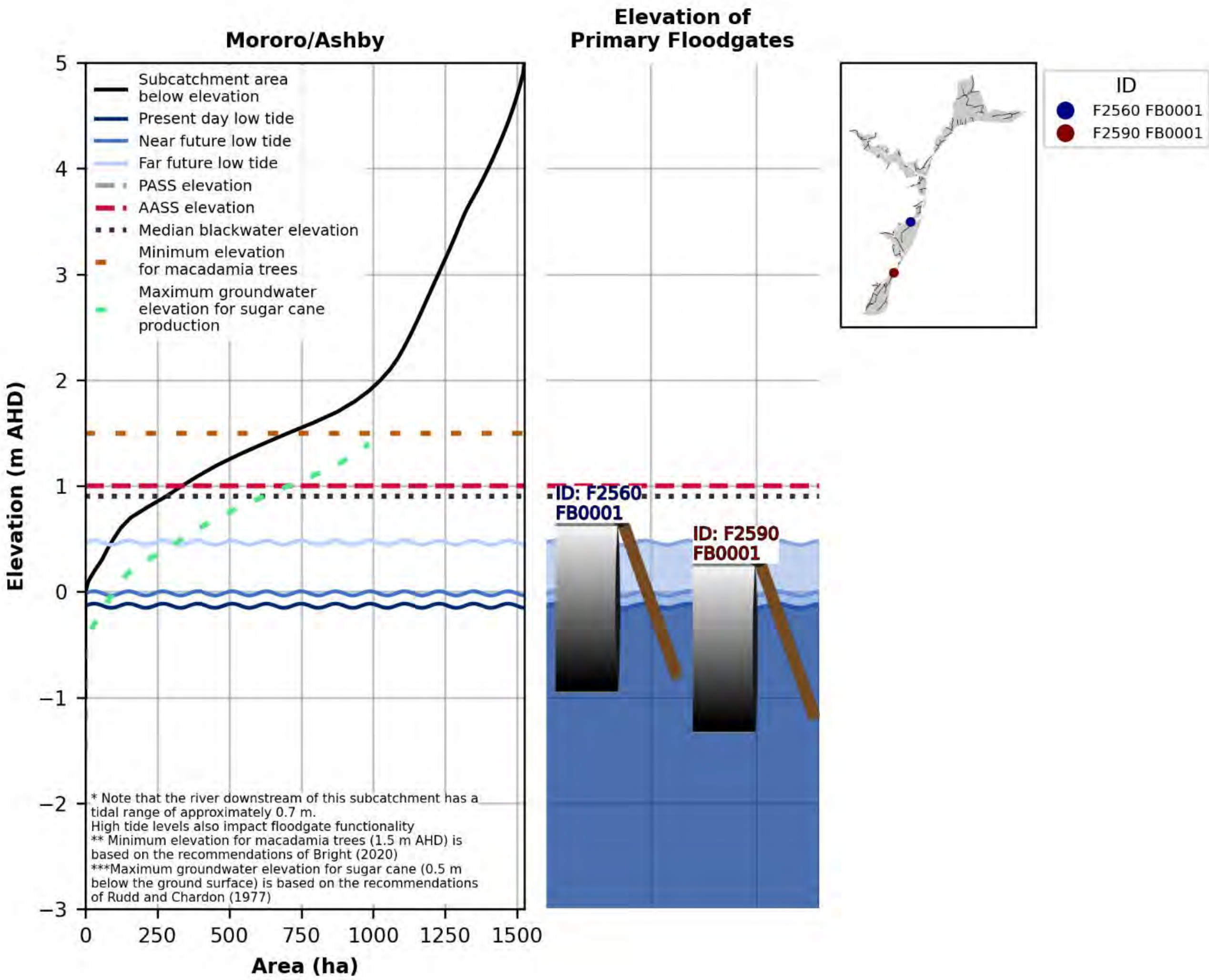

Figure 8-49: Primary floodgates and key floodplain elevations – Mororo/Ashby subcatchment

8.9.4 Management options

Short-term management options

Approximately a quarter of this subcatchment is used for grazing, mostly in the lowest areas. Where current land use allows, wet pasture management should be encouraged through the installation of dropboard weirs and infilling of minor drainage networks. This will limit further acidification of ASS and reduce groundwater drawdown and subsequent acid drainage. Any plans for wet pasture management would require the cooperation and input from local landholders to ensure the resulting pasture is appropriate for their stock or needs. Where possible, tidal flushing should also be maximised through modification of existing floodgate infrastructure.

It is also recommended that drainage networks in the existing sugar cane farms be investigated and, where necessary, artificial drainage networks be reshaped to the mean low water (MLW) levels in the Clarence River to prevent unnecessary groundwater drainage. Pumping systems were observed in the Mororo/Ashby subcatchment during field investigations. Where possible, pumping should be actively managed and limited to prevent unnecessary groundwater drawdown, which may further exacerbate acid sulfate soils oxidation.

This subcatchment also contains sensitive receivers (see Appendix J), including Coastal Management SEPP coastal wetlands along Mangrove Creek. Management and maintenance of these areas should be supported as they provide important habitat and biodiversity.

Long-term management options

Drainage of low-lying land in this subcatchment may be impacted by sea level rise in the near future. Due to the low-lying elevation of the area and its location in the lower estuary, natural estuarine hydrology could be restored if present day land uses are impacted by reduced drainage and become unproductive. This could be achieved through removing the main floodgates and redesigning the surrounding drainage system to shallow, wide drains to encourage overland flow of tidal water.

A summary of the recommended management options for the Mororo/Ashby subcatchment is provided in Table 8-14.

Table 8-14: Summary of management options for Mororo/Ashby subcatchment

Timeframe	Strategy	Effectiveness at improving: Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Floodgate modification	Moderate	Small	Negligible
Short-term	Wet pasture management	None	Moderate	Moderate
Long-term	Restoration of natural estuarine hydrology	Moderate	Moderate	Limited

8.10 The Broadwater subcatchment

Acid priority rank:	**8**
Blackwater priority rank:	**8**
Infrastructure	
Approximate waterway length (km)	43
# Privately owned end of system structures	2
# Publicly owned end of system structures	11
# End of system structures within coastal wetlands	4
# Publicly owned end of system structures within coastal wetlands	4
Primary floodplain infrastructure (ID):	F-2490-FB-0001, F-2500-FB-0001
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.2 to 0.5
Approximate AASS elevation (m AHD)	0.5
Approximate PASS elevation (m AHD)	0.2
Median blackwater elevation (m AHD)	1.3
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0.0
Far future low level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	27.1
Saltmarsh (km)	Within subcatchment
Seagrass (km)	18.3
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	3,347
Classified as conservation and minimal use (ha (%))	93 (3%)
Classified as grazing (ha (%))	664 (20%)
Classified as forestry (ha (%))	26 (1%)
Classified as sugar cane (ha (%))	314 (9%)
Classified as horticulture (ha (%))	4 (0%)
Classified as other cropping (ha (%))	309 (9%)
Classified as urban/industrial/services (ha (%))	82 (2%)
Classified as marsh/wetland (ha (%))	1,747 (51%)
Other (ha (%))	109 (3%)
Land values	
Estimated total primary production value ($/year)	$1,600,000
Average land value above 1.3 m AHD ($/ha)	$3,600
Average land value below 1.3 m AHD ($/ha)	$2,900

8.10.1 Site description

The Broadwater subcatchment is situated on the left bank of the Clarence River, between Lawrence and Maclean. It includes a large waterbody (known as The Broadwater) which is located within Crown Land (shown in Figure 8-50). More than 50% of the subcatchment is classified as Marsh/Wetland area which is primarily located on the low areas along the banks of The Broadwater, being situated mostly below +0.5 m AHD. A plan of management was developed for The Broadwater (Department of Environment and Conservation (NSW), 2006) in recognition of its important ecological value, particularly with respect to migratory birds.

The land to the north-west of The Broadwater is primarily used for grazing, while the area adjacent to the Clarence River to the south-west is mostly used for sugar cane. The primary drainage and topography of the subcatchment is shown in Figure 8-51.

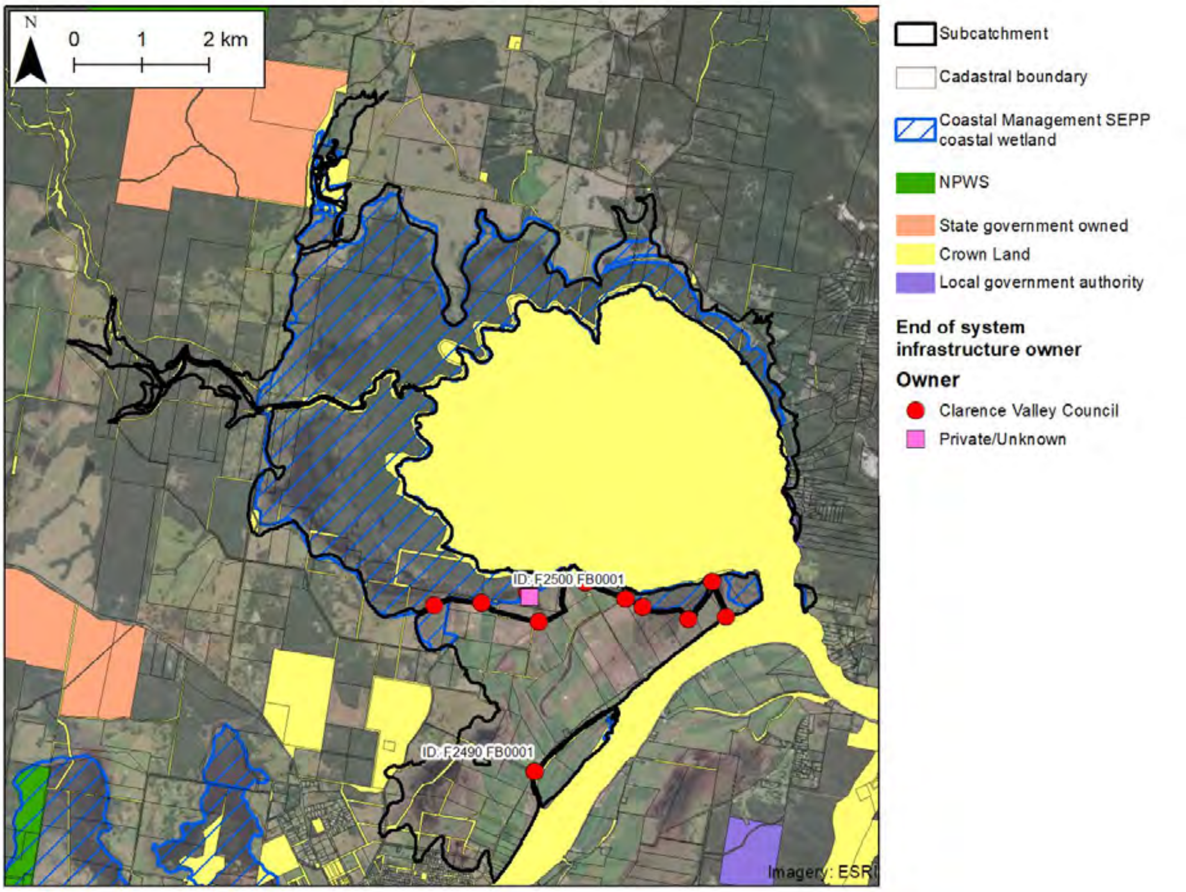

Figure 8-50: The Broadwater subcatchment - land and end of system infrastructure tenure

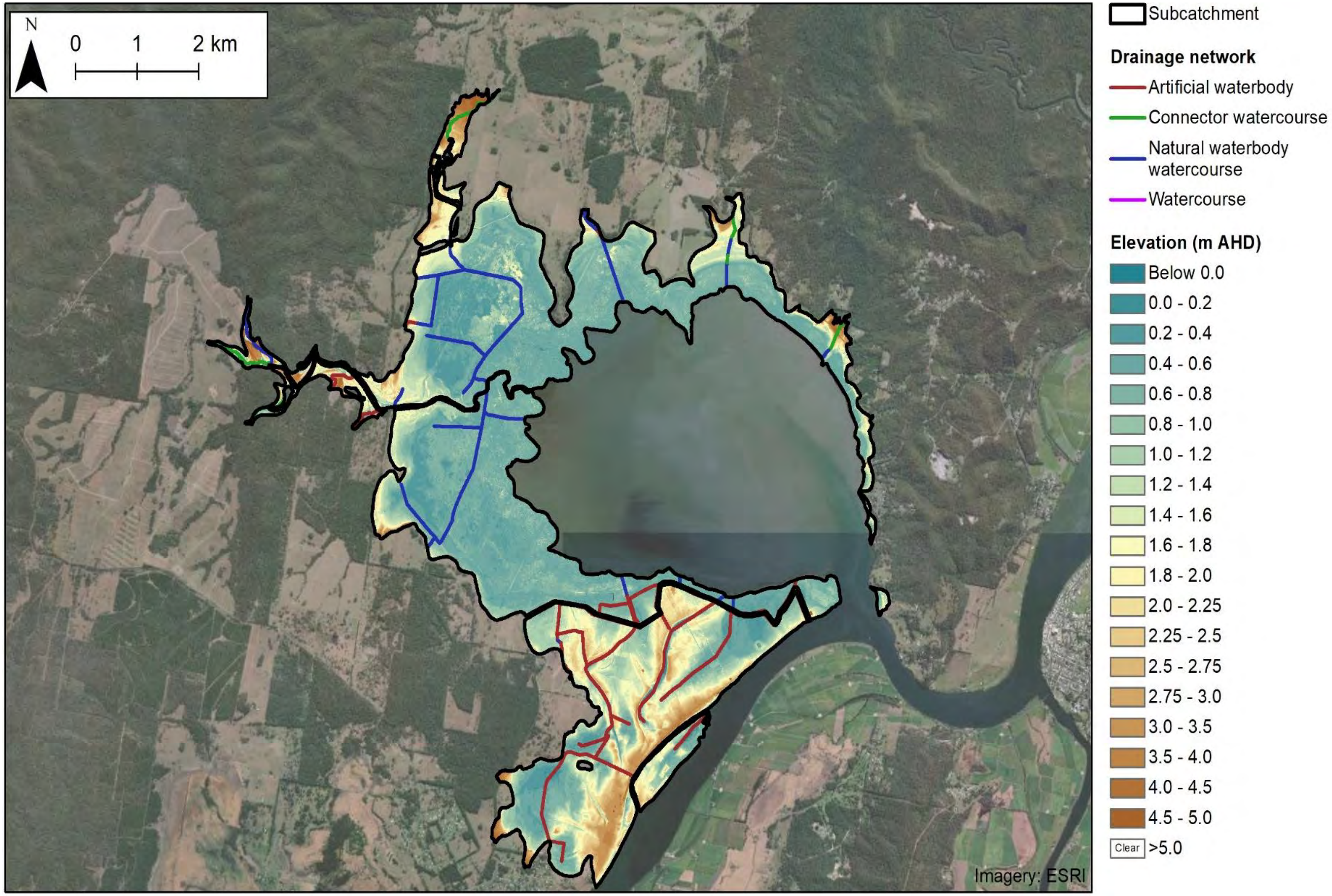

Figure 8-51: The Broadwater Creek subcatchment elevation and drainage network

8.10.2 History of remediation

One (1) of the floodgates in the Broadwater subcatchment has been modified through the installation of an auto-tidal buoyancy gate, as well as a vertical lifting device on a main drain off Kings Channel (floodgate ID F-2490-FT-0001), shown in Figure 8-52. In addition, a water control structure (structure ID F-2500-FH-0002) has also been installed on Kings Drain No. 1. CVC data indicates that this structure is a head and discharge structure, which acts as a removeable weir. This structure was not inspected during field investigations, however this structure would act to maintain higher groundwater tables in the upstream drainage system.

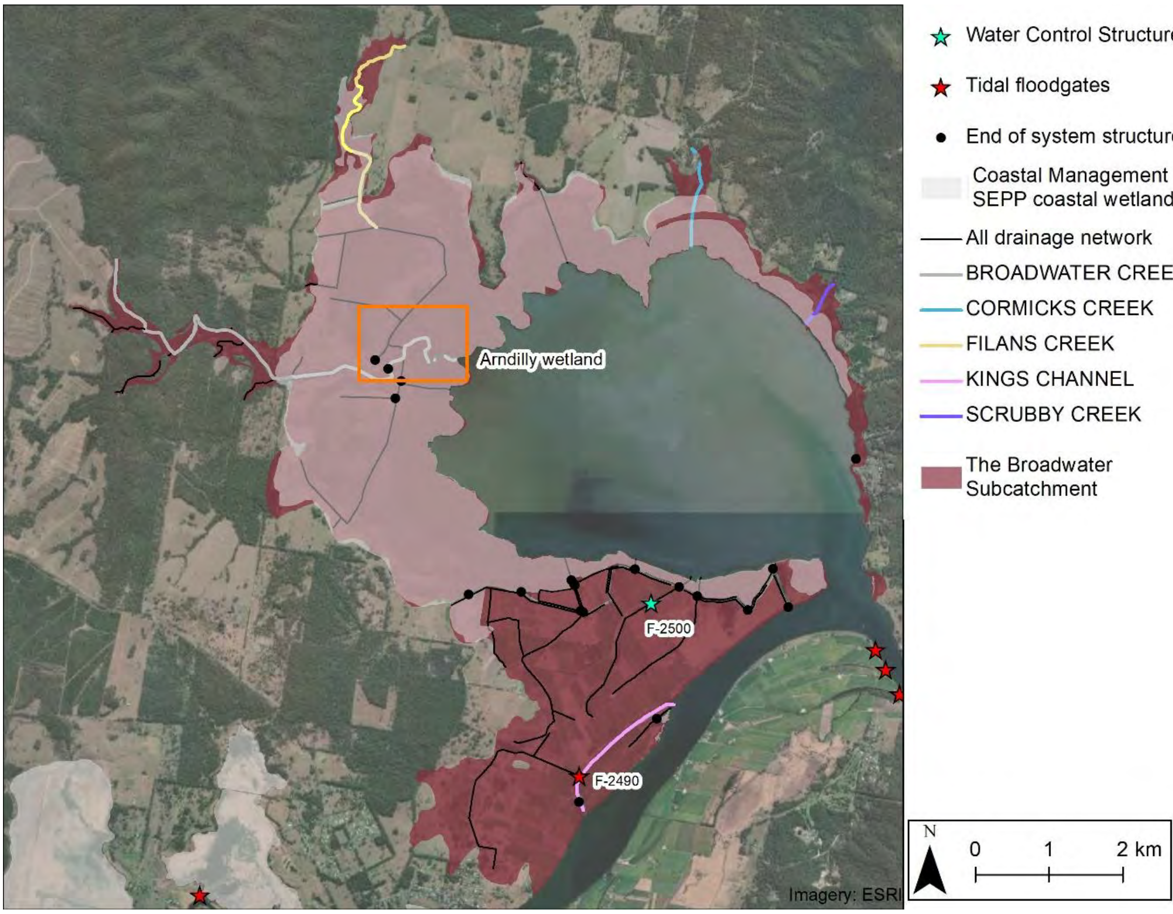

Figure 8-52: The Broadwater subcatchment including previous remediation actions

Arndilly Wetland, situated on private land, is highlighted in Figure 8-52. The wetland is disconnected from the Broadwater through a levee system, culvert and floodgate (WRL, 2011). The landholder has been actively managing the wetland to improve environmental outcomes, including managing private drainage structures to increase the water table and prevent ASS drainage (Smith, 2010). In 2011, WRL worked with the local landholder to assess whether additional drainage controls could be constructed to allow the dry weather water levels in the wetland to be maintained at +0.1 m AHD to reduce acid drainage as well as ensuring drainage of the wetland within 5 – 7 days after rainfall events. The assessment showed that the discharge culvert and drainage channel would need to be significantly larger to provide the drainage required to meet the drainage criteria after rainfall.

Figure 8-52 also highlights the area mapped as Coastal Management SEPP coastal wetlands. This classification means that the area is subject to more stringent development controls under state government legislation.

Sugar cane farms in the Clarence River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in The Broadwater subcatchment were not obtained, cane farms typically implement the following ASS management actions:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.10.3 Floodplain drainage - sea level rise vulnerability

Figure 8-53 summarises the sea level rise vulnerability in The Broadwater subcatchment. The majority of the area that is presently mapped as Coastal Management SEPP coastal wetlands (see Figure 8-52) will be medium risk in the far future. Some of these areas will transition from freshwater wetlands to brackish wetlands as water levels rise. Reduced drainage and higher salinity may impact the grazing land upstream of the existing Coastal Wetlands. The low areas (<0.8 m AHD) in the south-western section of this subcatchment (primarily used for sugar cane) may also become increasingly vulnerable to reduced drainage in the near to far future.

Floodgates within The Broadwater subcatchment will also be affected by sea level rise, with four (4) secondary structures classified as 'Most vulnerable' in the near future increasing to nine (9) secondary structures in the far future. Primary structure F-2490-FB-0001 is classified as 'Moderately vulnerable' in the far future.

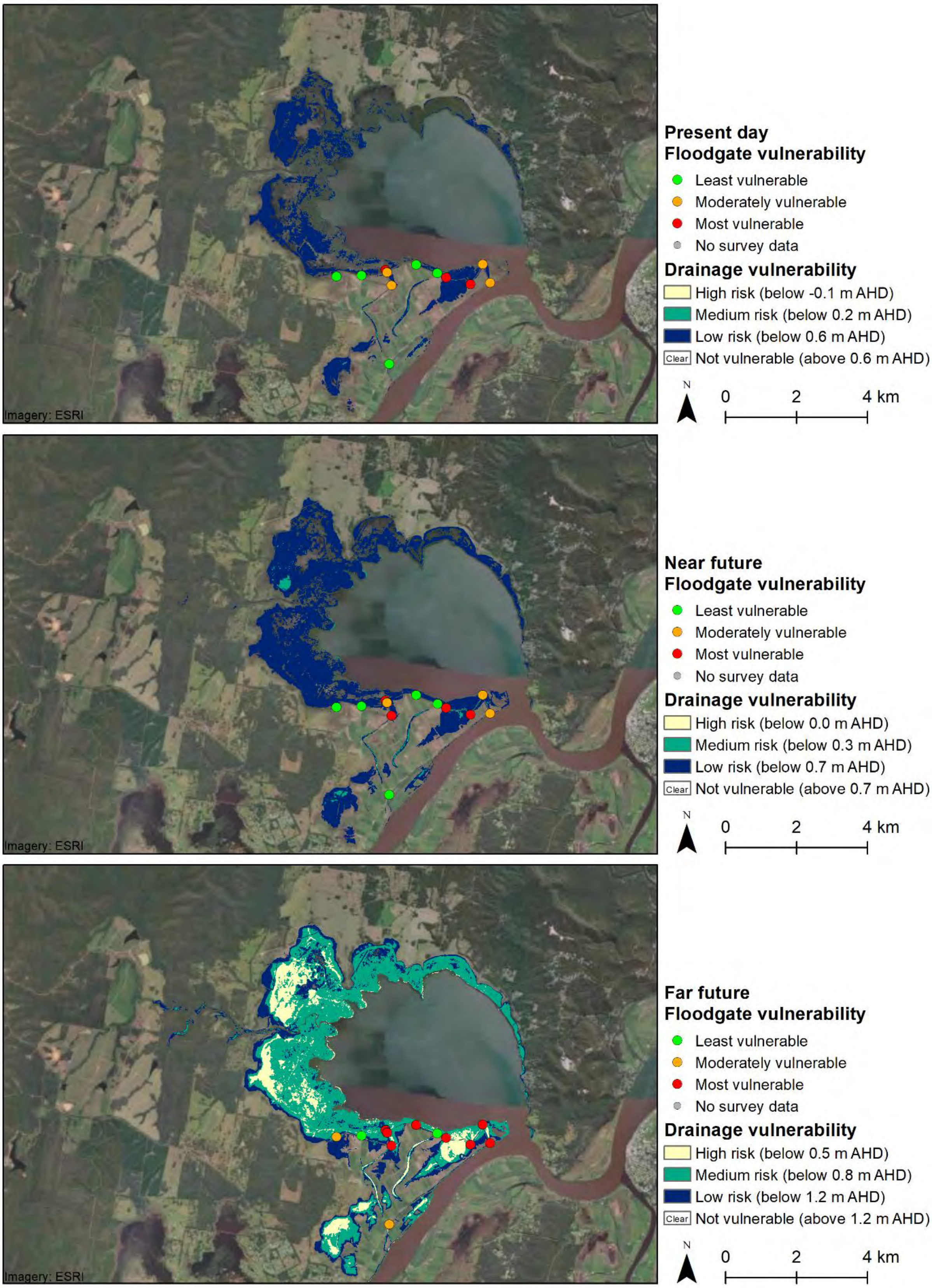

Figure 8-53: Sea level rise drainage vulnerability – The Broadwater subcatchment

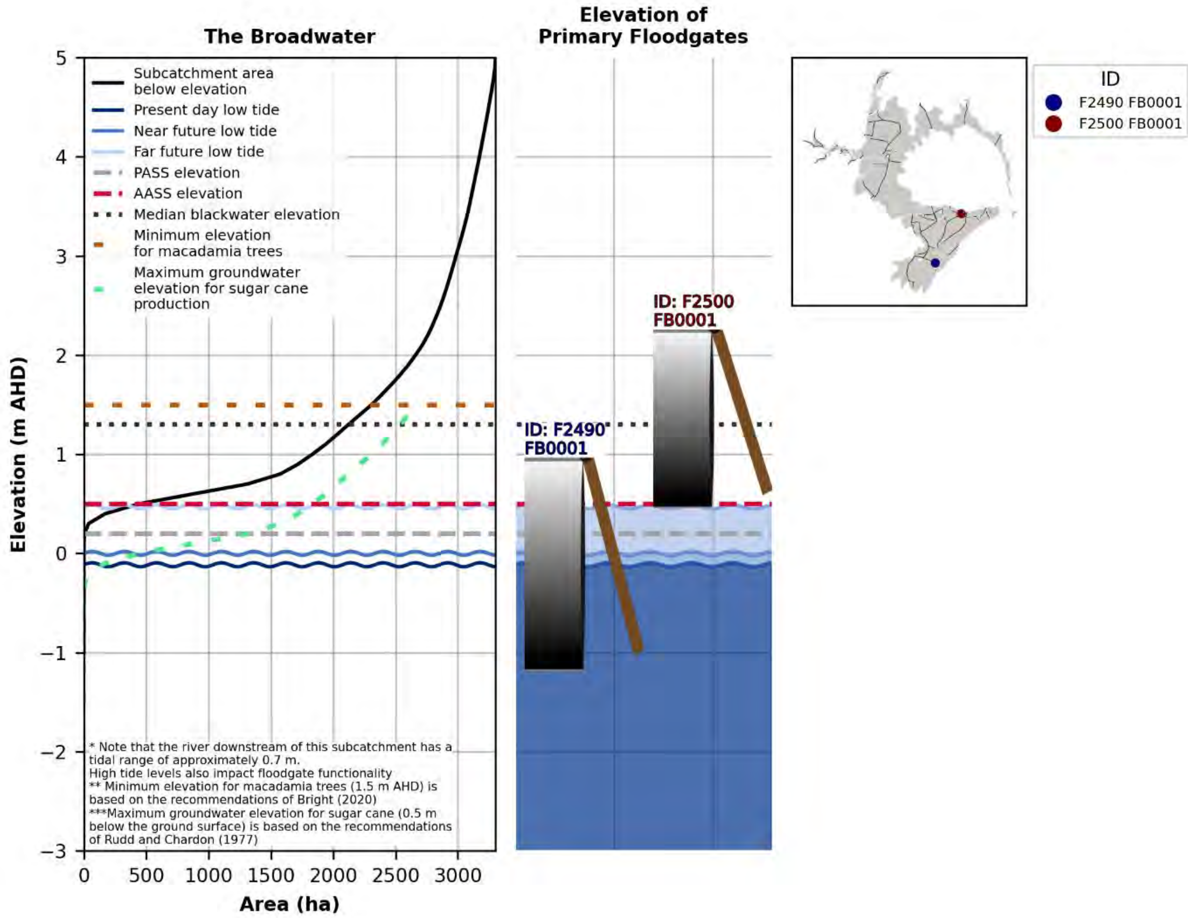

Figure 8-54: Primary floodgates and key floodplain elevations – The Broadwater subcatchment

8.10.4 Management options

Short-term management options

Reducing acid export via drain modification, such as infilling or reshaping of artificial drainage around the banks of The Broadwater will help reduce further acidification of the soil and acid drainage. Soil data in the area showed that high acidity (pH<4) soils exist at elevations between +0.3 to -1.5 m AHD, so any artificial drainage in this area is likely to intersect acidic soils.

Soil acidity was generally observed to be higher in the Kings Creek area (pH ~ 5 and above). However, improvements in general water quality and aquatic connectivity may still be achieved through controlled tidal flushing. Other major floodgates in this area should be assessed and considered for modification to allow tidal flushing. Allowing managed tidal inflows would encourage acid buffering, improved flushing, and increase aquatic habitat in the subcatchment.

Long-term management options

As discussed in Section 8.10.3, sea level rise will result in the expansion of The Broadwater intertidal area. As this occurs, this land should be managed as estuarine wetlands, and natural hydrological flow paths should be encouraged. If the land uses upstream of the coastal wetland are affected by reduced drainage or increased salinity, the drainage network should be re-designed to be shallow, wide drainage systems that have reduced interaction with acidic soil layers.

Land uses in the south-western section of The Broadwater subcatchment may also be affected by reduced drainage in the future. Where present day land uses cannot persist (or present land use allows), wet pasture management should be encouraged to maintain higher groundwater tables and reduce acid drainage, while maintaining agricultural productivity. This could be achieved through reducing drainage density by infilling secondary drainage and the use of localised dropboard weirs. The lowest lying areas may become permanently inundated in the future due to sea level rise. Any plans for wet pasture management would require the cooperation and input from local landholders to ensure the resulting pasture is appropriate for their stock or needs.

A summary of the recommended management options for the Broadwater subcatchment is provided in Table 8-15.

Table 8-15: Summary of management options for The Broadwater subcatchment

Timeframe	Strategy	Effectiveness at improving: Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Floodgate modification	Moderate	Small	Negligible
Short-term	Drain infilling	None	Moderate	Limited
Long-term	Estuarine wetlands	High	High	High
Long-term	Wet pasture management	None	Moderate	Moderate

8.11 Maclean subcatchment

Acid priority rank:	**9**
Blackwater priority rank:	**13**
Infrastructure	
Approximate waterway length (km)	18
# Privately owned end of system structures	1
# Publicly owned end of system structures	26
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	F-2640-FB-0001, F-2640-FP-0001, F-2590-FB-0001
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-0.9 to -0.4
Approximate AASS elevation (m AHD)	0.2
Approximate PASS elevation (m AHD)	-0.4
Median blackwater elevation (m AHD)	0.9
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	0.0
Far future low level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	17.0
Saltmarsh (km)	4.3
Seagrass (km)	8.2
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	923
Classified as conservation and minimal use (ha (%))	314 (34%)
Classified as grazing (ha (%))	135 (15%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	161 (17%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	2 (0%)
Classified as urban/industrial/services (ha (%))	143 (16%)
Classified as marsh/wetland (ha (%))	155 (17%)
Other (ha (%))	11 (1%)
Land values	
Estimated total primary production value ($/year)	$500,000
Average land value above 0.9 m AHD ($/ha)	$20,500
Average land value below 0.9 m AHD ($/ha)	$7,700

8.11.1 Site description

The Maclean subcatchment is located in the mid-estuary of the Clarence River floodplain, and includes the Yaegl Nature Reserve which accounts for more than 30% of the subcatchment area (Figure 8-55). Maclean is a regional town with a population of around 2,600 people (in the 2016 census). CVC maintains a flood levee, as well as 25 floodgates, along the western half of the subcatchment to manage flood impacts to the town of Maclean. About 35% of this subcatchment is used for agriculture, consisting predominantly of grazing and sugar cane.

Apart from flood levee banks along the Clarence River, the majority of the Maclean subcatchment is relatively low (<0.8 m AHD). A network of artificial drains provide drainage to the low-lying areas used for agriculture, shown in Figure 8-56. The Yaegal Nature Reserve is connected to the Clarence River through a natural watercourse called James Creek.

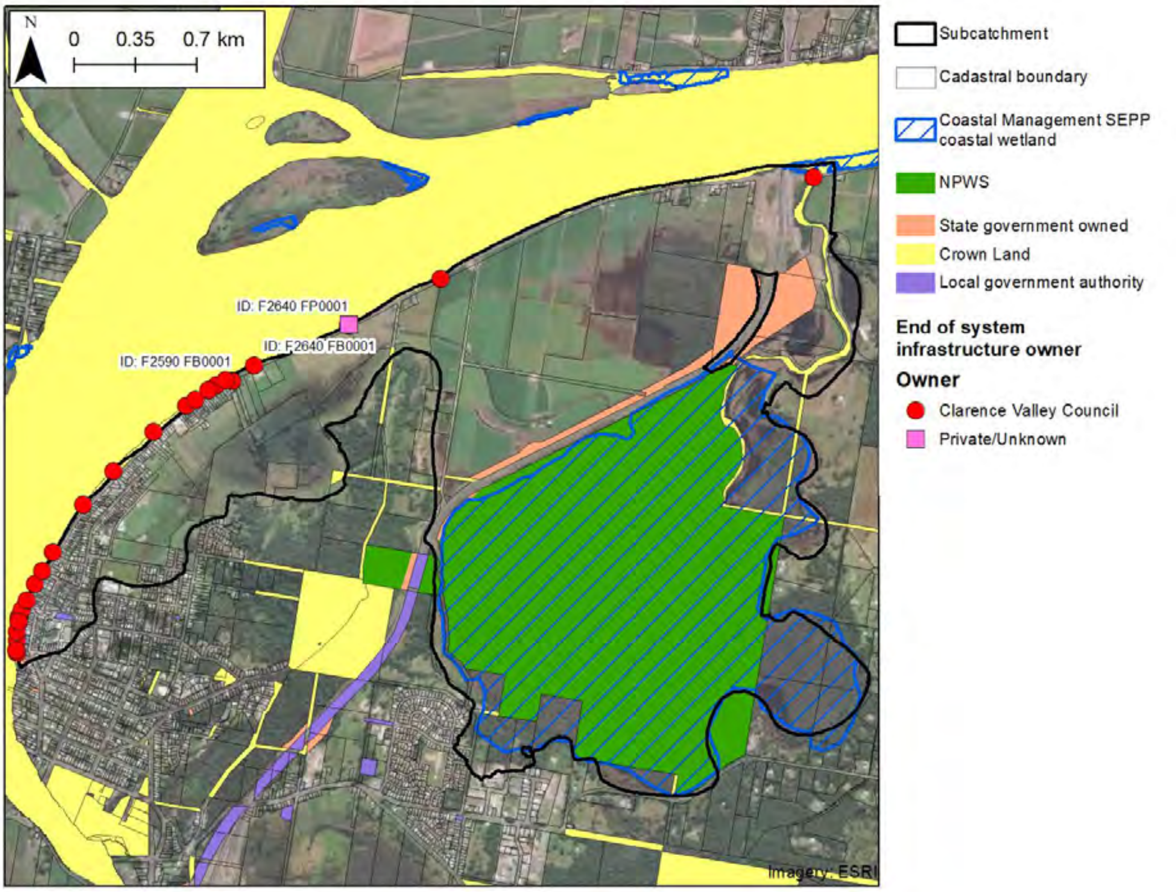

Figure 8-55: Maclean subcatchment - land and end of system infrastructure tenure

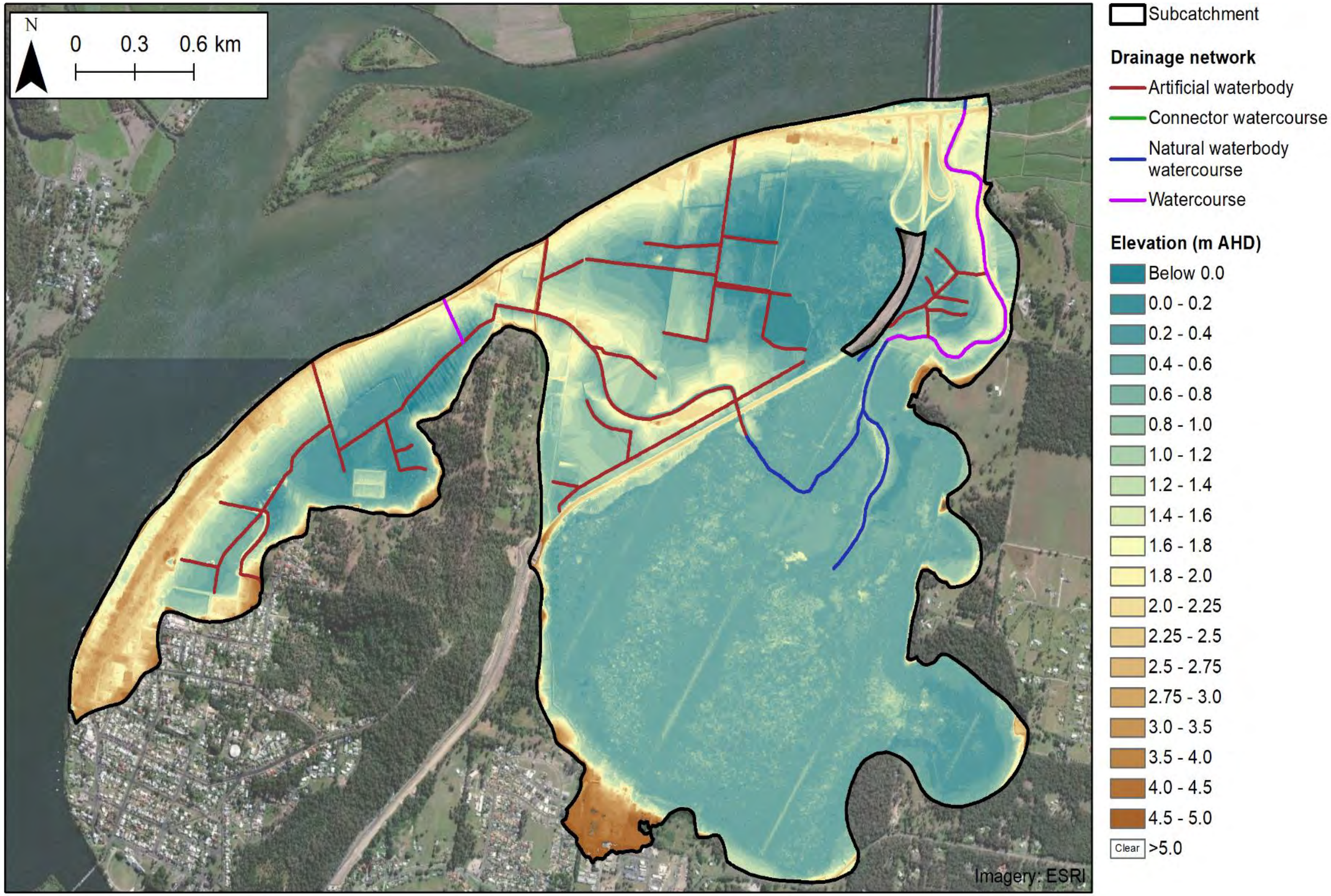

Figure 8-56: Maclean subcatchment elevation and drainage network

8.11.2 History of remediation

A significant section of the Maclean subcatchment is within the Yaegl Nature Reserve, shown in Figure 8-57. The Yaegl Nature Reserve Plan of Management (NPWS, 2011) acknowledged the presence of ASS in the nature reserve, and explicitly states no earthworks should be undertaken due to the risk of excavating and disturbing acidic soils.

CVC has modified at least three (3) of the major floodgates in the subcatchment with lifting devices to allow managed openings. The floodgates include floodgate ID F-2630-FB-0001, F-2640-FB-0001 and F-2670-FP-0001.

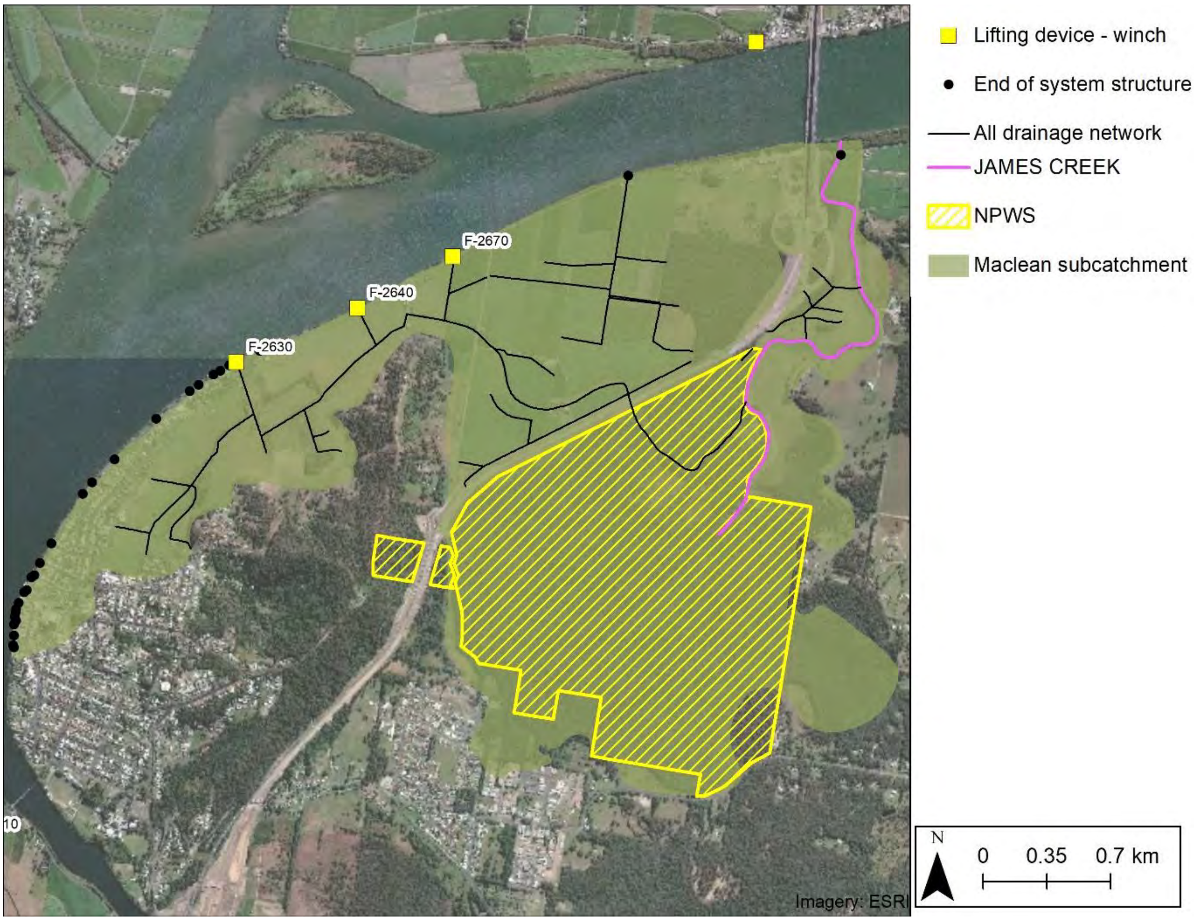

Figure 8-57: Maclean subcatchment including previous remediation actions

Sugar cane farms in the Clarence River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Maclean subcatchment were not obtained, cane farms typically implement the following ASS management actions:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.11.3 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability of the Maclean subcatchment is shown in Figure 8-58. The Yaegl Nature Reserve (which is connected through to the Clarence River through James Creek which is not floodgated) may be increasingly influenced by tidal overland flows as sea level rise occurs, which may result in a change in vegetation towards more water and salt tolerant species. The agricultural areas in the Maclean subcatchment are likely to be impacted by reduced drainage in the near to far future, particularly in areas below +0.4 m AHD. This may affect the productivity and viability of present day land uses.

The vulnerability assessment has also identified five (5) floodgates that are classified as 'Most vulnerable in the near future, including primary floodgate F-2590-FB-0001. This increases to 13 floodgates in the far future, including primary floodgate F-2640-FB-0001. This means that the future water levels in the Clarence river will be above the obvert of these structures at least 50% of the time. The elevation of primary floodgates compared to key elevations across the subcatchments is shown in Figure 8-59.

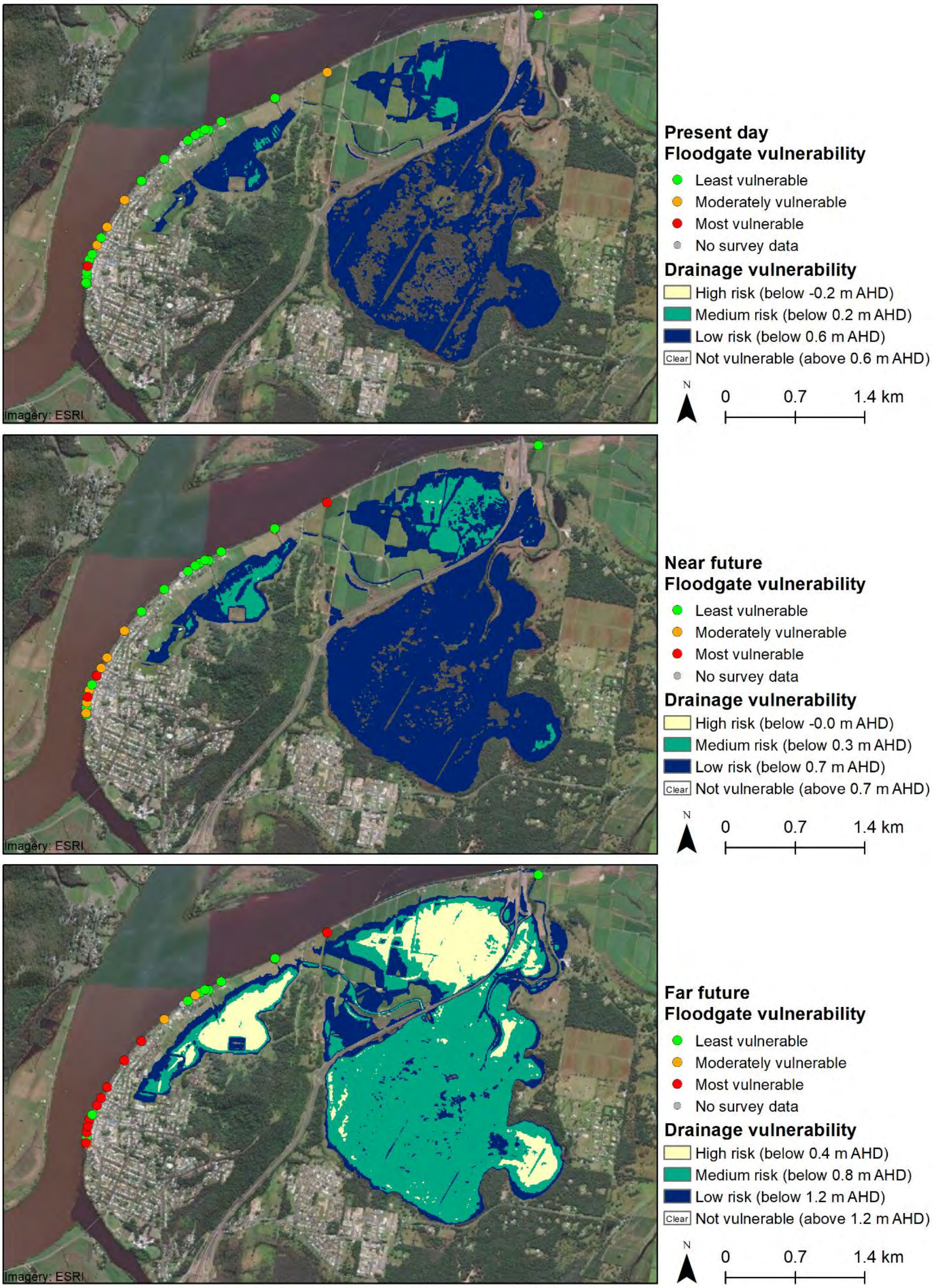

Figure 8-58: Sea level rise drainage vulnerability – Maclean subcatchment

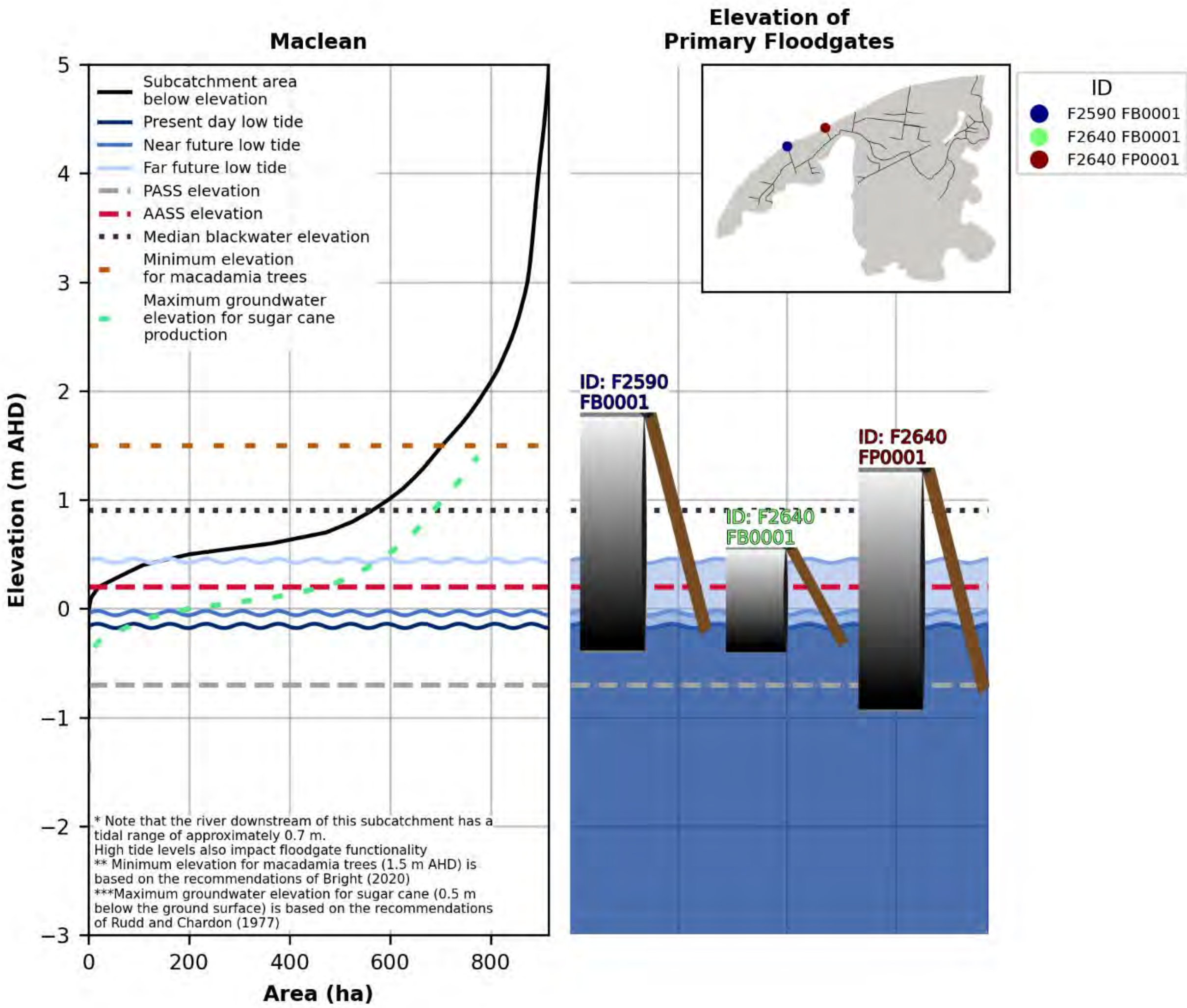

Figure 8-59: Primary floodgates and key floodplain elevations – Maclean subcatchment

8.11.4 Management options

Short-term management options

The Yaegl Nature Reserve covers over one third of the Maclean subcatchment. Management of this area should ensure drainage does not exacerbate ASS oxidisation in the Nature Reserve. Encouraging wet tolerant wetland species throughout the Nature Reserve would also reduce the likelihood of blackwater generated from the area.

Soil data in the low area east of Maclean indicates that the PASS layer is located at an elevation of approximately -0.6 m AHD (approximately 0.6 m below the surface). Drains should be surveyed in this area and where drain inverts are below this elevation, reshaping of the drainage network should be considered to raise the drain invert and reduce further oxidisation of ASS soils.

The management of the floodgates in this subcatchment should be regularly reviewed. Where possible, managed tidal flushing should be encouraged to allow natural buffering of acids. This could be achieved through existing winches, or through the installation of auto-tidal buoyancy gates. Changes to management of these floodgates would require consideration of any potential impacts to adjacent landholders.

Long-term management options

Reduced drainage in the future due to sea level rise may impact present day land uses in the Maclean subcatchment. If present day or productive land uses are no longer viable, low areas should be considered for restoration of natural hydrology, as has been implemented in the Nature Reserve. This may involve infilling or reshaping of the existing drainage network to encourage shallow freshwater or brackish inundation while maintaining connectivity with the Clarence River. This would increase surface water and groundwater levels, reduce acid drainage, and create aquatic habitat. The floodgate infrastructure could be maintained and managed to continue providing flood mitigation capacity to the Maclean township.

A summary of the recommended management options for the Maclean is provided in Table 8-16.

Table 8-16: Summary of management options for Maclean subcatchment

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Active floodgate management	Moderate	Small	Negligible
Long-term	Restoration of natural estuarine hydrology	Limited	High	Moderate

8.12 Harwood/Chatsworth/Goodwood/Warregah Islands subcatchment

Acid priority rank:	**10**
Blackwater priority rank:	**9**
Infrastructure	
Approximate waterway length (km)	105
# Privately owned end of system structures	13
# Publicly owned end of system structures	50
# End of system structures within coastal wetlands	2
# Publicly owned end of system structures within coastal wetlands	2
Primary floodplain infrastructure (ID):	F-2820-FT-0001, F-2830-FT-0001, F-2860-FB-0001, F-2890-FB-0001, F-2910-FB-0001, F-2920-LD-0001, F-2940-LD-0001, F-2950-FB-0001, F-3000-FB-0001, F-3090-FB-0001, F-3100-FB-0001
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.3 to -0.5
Approximate AASS elevation (m AHD)	0.2
Approximate PASS elevation (m AHD)	-0.4
Median blackwater elevation (m AHD)	0.9
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	-0.1
Far future low level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	4.9
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	4,016
Classified as conservation and minimal use (ha (%))	40 (1%)
Classified as grazing (ha (%))	348 (9%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	3,295 (82%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	23 (1%)
Classified as urban/industrial/services (ha (%))	169 (4%)
Classified as marsh/wetland (ha (%))	19 (0%)
Other (ha (%))	122 (3%)
Land values	
Estimated total primary production value ($/year)	$9,800,000
Average land value above 0.9 m AHD ($/ha)	$9,700
Average land value below 0.9 m AHD ($/ha)	$6,500

8.12.1 Site description

The Harwood/Chatsworth/Goodwood/Warregah Islands subcatchment includes four (4) separate islands in the lower Clarence River, shown in Figure 8-60. Sugar cane accounts for approximately 80% of the land use in this subcatchment, covering the majority of each of the four (4) islands. The Harwood Sugar Mill also operates in this subcatchment.

As shown in Figure 8-61, topography is generally higher than 1 m AHD and has an extensive drainage network. At least 54 floodgates exist across the islands, facilitating drainage for agricultural land uses, the majority of which are managed by CVC. CVC maintain flood levees around some sections of Goodwood Island (eastern most island) to manage the impacts of small flood events.

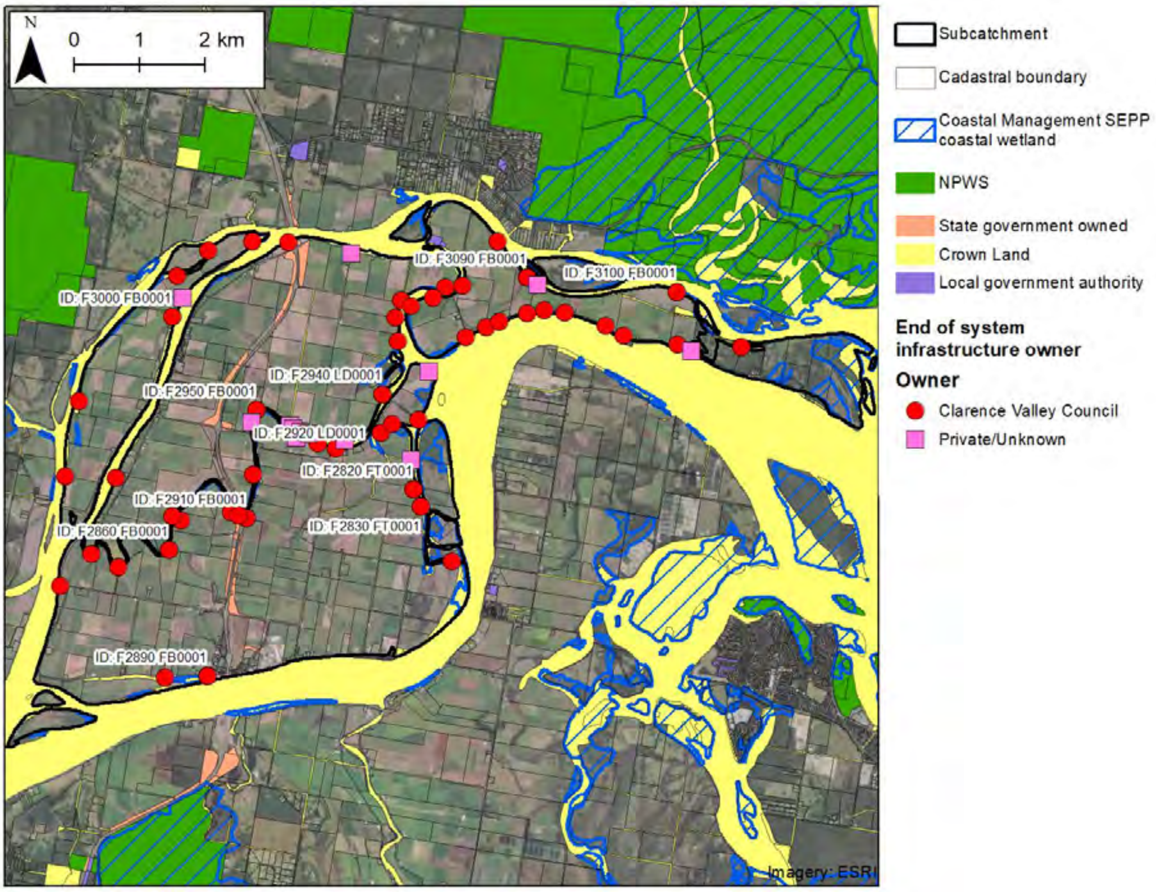

Figure 8-60: Harwood/Chatsworth/Goodwood/Warregah Islands subcatchment - land and end of system infrastructure tenure

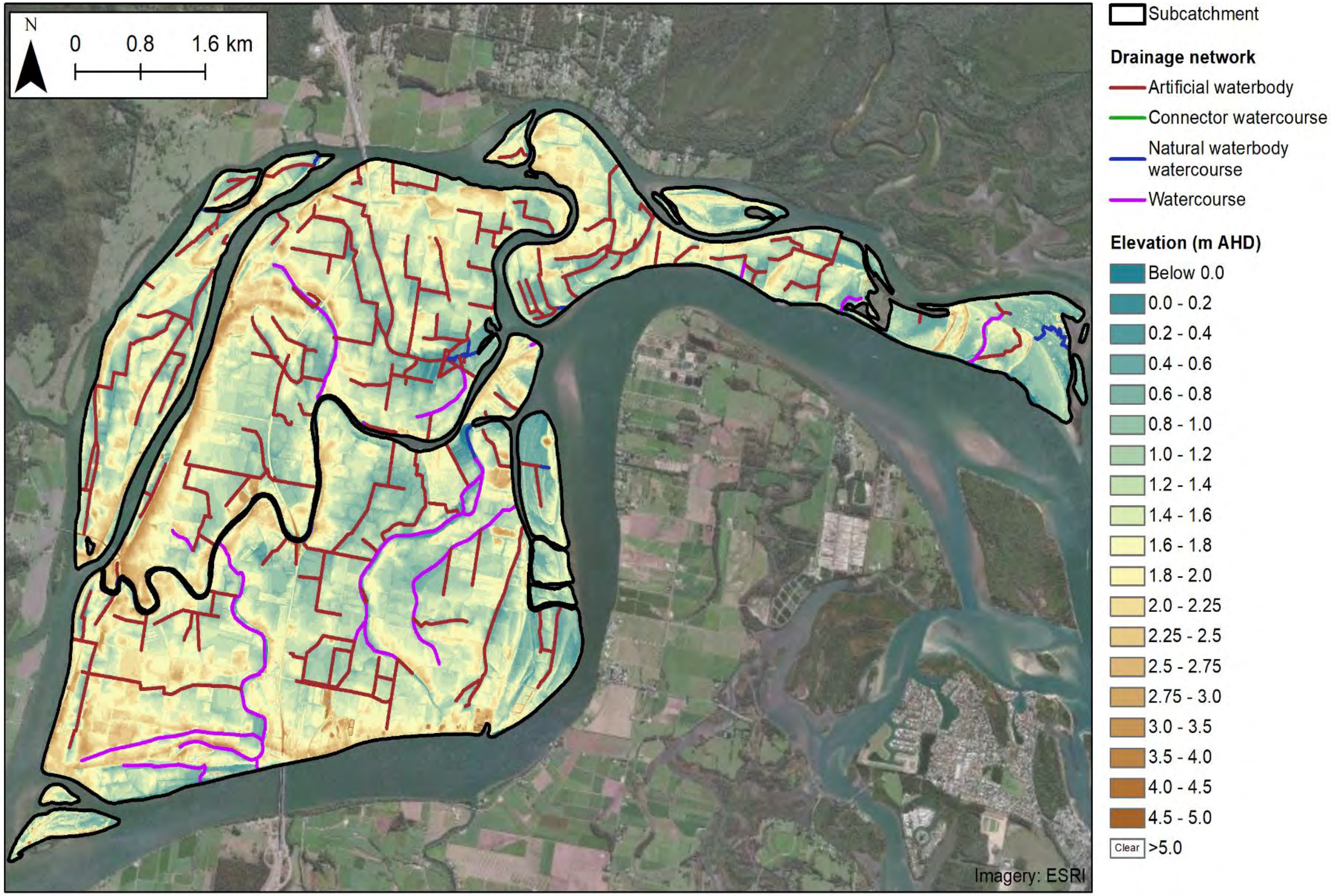

Figure 8-61: Harwood/Chatsworth/Goodwood/Warregah Island subcatchment elevation and drainage network

8.12.2 History of remediation

All of the primary drainage infrastructure in the Harwood/Chatsworth/Goodwood/Warregah Island subcatchment have been modified to allow controlled tidal flushing as part of the Clarence Floodplain Project, highlighted in Figure 8-62. Information on modified floodgates was provide by CVC and supplemented by WRL field investigations. There are 13 floodgates in this subcatchment that have been modified with an auto-tidal buoyancy gate and a lifting device, an example of which is shown in Figure 8-63. While the modified floodgates typically only have one (1) buoyancy gate, the ability to lift maybe on one (1) or many floodgates. A 14th floodgate (floodgate ID F-3100-FB-0001) has been modified just an auto-tidal buoyancy gate only (no lifting device).

Sugar cane farms in the Clarence River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Harwood/Chatsworth/Goodwood/Warregah Island subcatchment were not obtained, cane farms typically implement the following ASS management actions:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

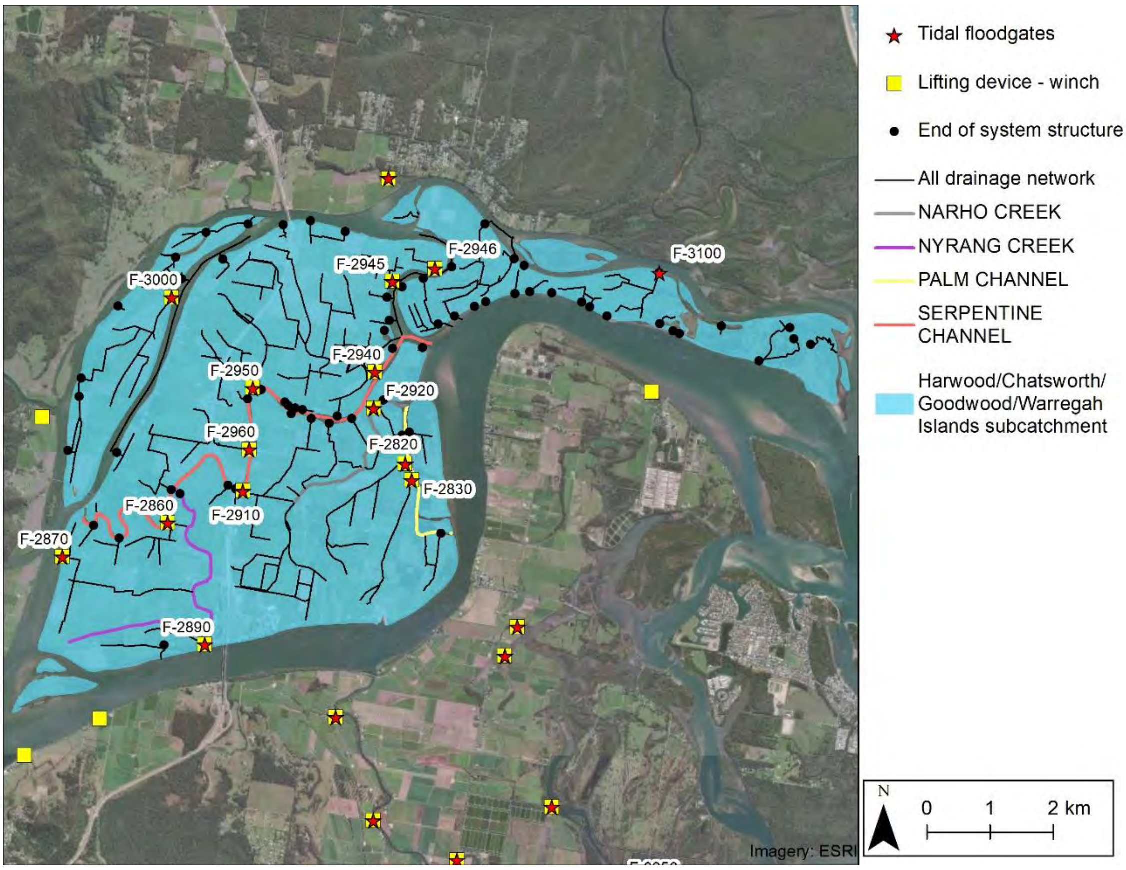

Figure 8-62: Harwood/Chatsworth/Goodwood/Warregah Island subcatchment including previous remediation actions

Figure 8-63: Example of a modified floodgate with a buoyancy gate and lifting device on the right bank floodgate (Floodgate ID F-2910-FB-0001)

8.12.3 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability of the Harwood/Chatsworth/Goodwood/Warregah Island subcatchment is summarised in Figure 8-64 and the elevation of primary floodgates compared to key elevations across the subcatchments is shown in Figure 8-65. The assessment showed that ten (10) floodgates are 'Most vulnerable' in the near future, including primary floodgate F3090-FB-0001. This increases to 47) 'Most vulnerable' structures in the far future, including all primary floodgates except F-2820-FT-0001. Only one (1) structure remains classified as 'Least vulnerable' in the far future.

The floodplain topography in this subcatchment is relatively high (mostly above 1 m AHD). However, Figure 8-64 shows that there are areas that will be progressively impacted by reduced drainage, particularly in the far future, which may impact present day land productivity. Sea level rise may also impact average groundwater levels throughout the subcatchment.

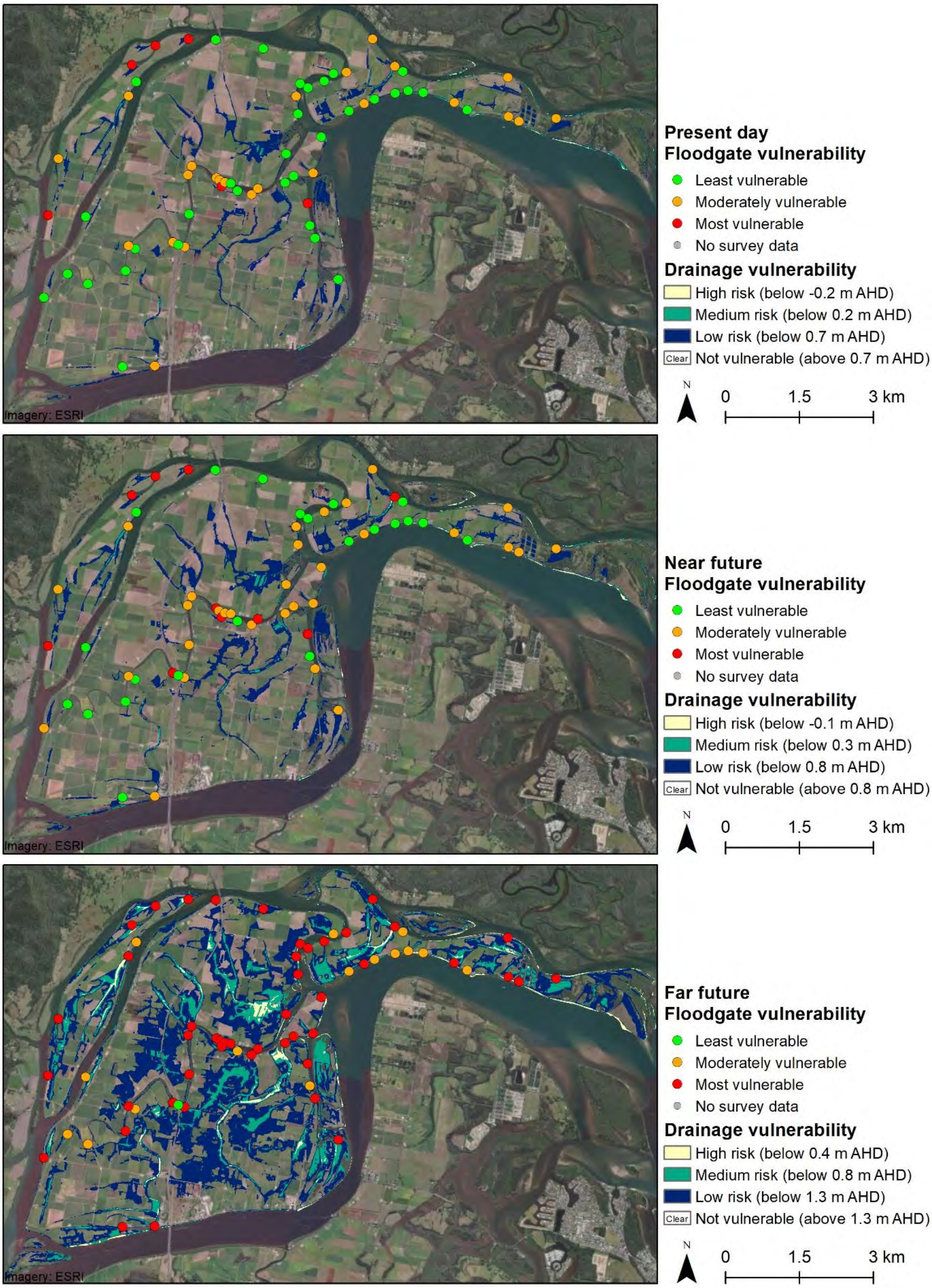

Figure 8-64: Sea level rise drainage vulnerability – Harwood/Chatsworth/Goodwood/Warregah Islands subcatchment

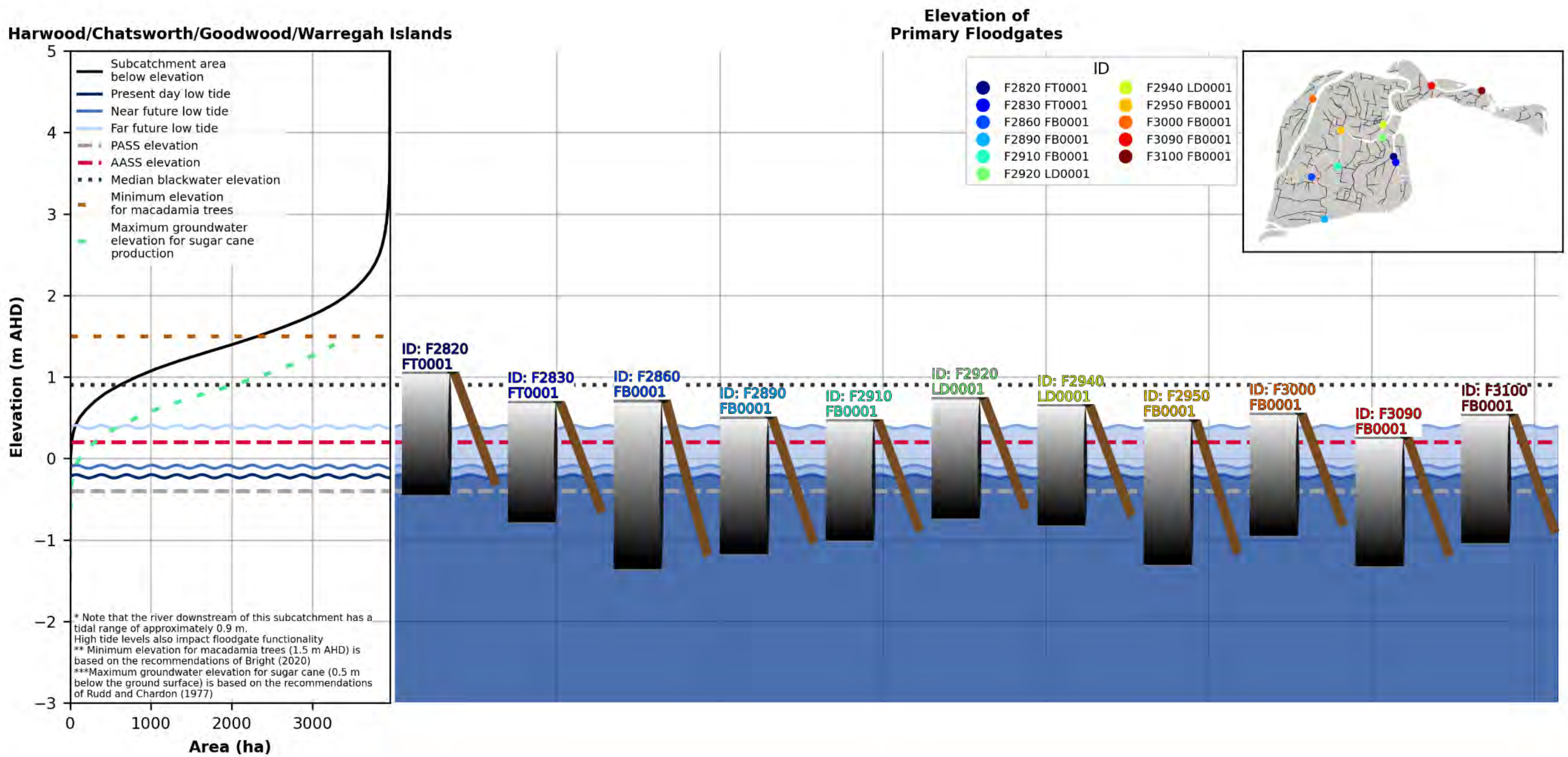

Figure 8-65: Primary floodgates and key floodplain elevations – Harwood/Chatsworth/Goodwood/Warregah Islands subcatchment

8.12.4 Management options

Short-term management options

At least 14 of the floodgates in this subcatchment have already been modified by Clarence Valley Council to allow managed tidal flushing. These floodgate modifications have already opened a significant waterway area to fish passage and will also allow natural buffering to any acid discharges during dry periods. Tidal flushing also improves overall water quality in the subcatchment.

However, additional/optimised tidal flushing may result in some improved water quality and increased fish passage and habitat. All floodgates should be reviewed and assessed for modification to allow increased tidal flushing. Acidity was observed to be worse on the south-western side of Goodwood Island (pH ~ 4). Modification of floodgates in this area should be investigated to provide natural buffering of acidic discharges.

Long-term management options

As sea level rise continues to occur, present day land uses may be affected by reduced drainage, increased groundwater table and increased groundwater salinity. Where present day land uses cannot persist, low areas should be considered for restoration of natural estuarine hydrology. The remediation would likely include removal of floodgates, infilling of secondary drains and removal of paddock scale levees. This would create intertidal habitat, as well as reducing acid and blackwater drainage from the subcatchment. Any changes to the drainage system will need to be completed with consideration of the potential social and economic impacts on local landholders.

A summary of the recommended management options for the Harwood/Chatsworth/Goodwood/ Warregah Island subcatchment is provided in Table 8-17.

Table 8-17: Summary of management options for Harwood/Chatsworth/Goodwood/Warregah Island subcatchment

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Active floodgate management	Moderate	Small	Negligible
Long-term	Localised restoration of natural estuarine hydrology	High	High	Moderate

8.13 Palmers Island/Micalo Island/Yamba subcatchment

Acid priority rank:	**11**
Blackwater priority rank:	**14**
Infrastructure	
Approximate waterway length (km)	136
# Privately owned end of system structures	12
# Publicly owned end of system structures	22
# End of system structures within coastal wetlands	3
# Publicly owned end of system structures within coastal wetlands	3
Primary floodplain infrastructure (ID):	F-3170-FB-0001, F-3200-FP-0001, F-3210-FB-0001, F-3220-FP-0001, F-3250-FP-0004
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.2 to -0.5
Approximate AASS elevation (m AHD)	-0.1
Approximate PASS elevation (m AHD)	-0.2
Median blackwater elevation (m AHD)	0.5
Present day low water level (m AHD)	-0.3
Near future low water level (m AHD)	-0.1
Far future low level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	Within subcatchment
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	4,548
Classified as conservation and minimal use (ha (%))	534 (12%)
Classified as grazing (ha (%))	1,215 (27%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	1,188 (26%)
Classified as horticulture (ha (%))	8 (0%)
Classified as other cropping (ha (%))	156 (3%)
Classified as urban/industrial/services (ha (%))	924 (20%)
Classified as marsh/wetland (ha (%))	215 (5%)
Other (ha (%))	308 (7%)
Land values	
Estimated total primary production value ($/year)	$4,300,000
Average land value above 0.5 m AHD ($/ha)	$14,700
Average land value below 0.5 m AHD ($/ha)	$8,700

8.13.1 Site description

Palmers Island/Micalo Island/Yamba subcatchment is located on the right bank of the Clarence River, near the ocean entrance. The subcatchment is interconnected by a number of tidal creeks and channels, shown in Figure 8-66 and Figure 8-67. Prior to flood mitigation works, Palmers Island was part of the tidal foreshore of the Wooloweyah Lagoon, however the construction of levee banks isolated Palmers Island from the lake (Clarence Valley Council, 2010).

Construction of artificial drainage networks and levees, shown in Figure 8-67, have enabled the expansion of sugar cane and grazing to areas that were previously wetlands, and drainage infrastructure (e.g. floodgates) have diminished available aquatic and intertidal habitat.

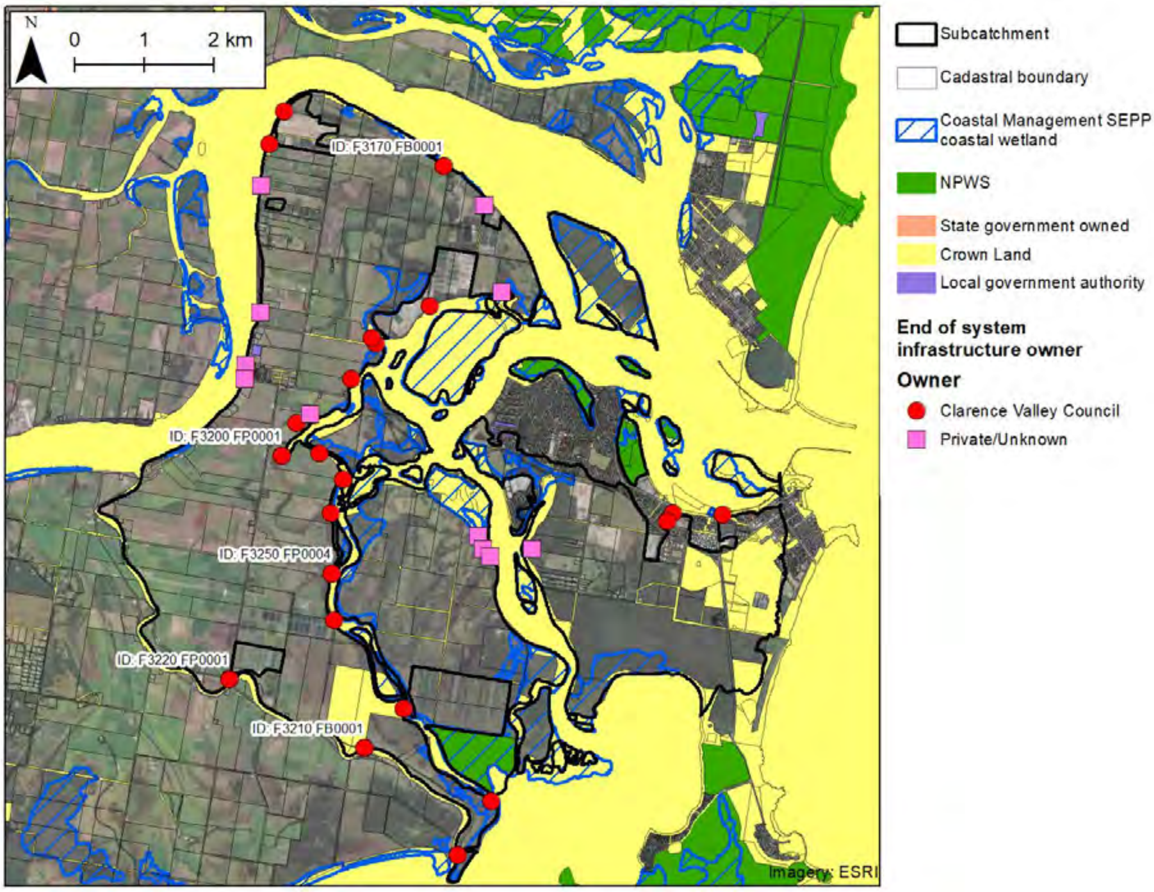

Figure 8-66: Palmers Island/Micalo Island/Yamba subcatchment - land and end of system infrastructure tenure

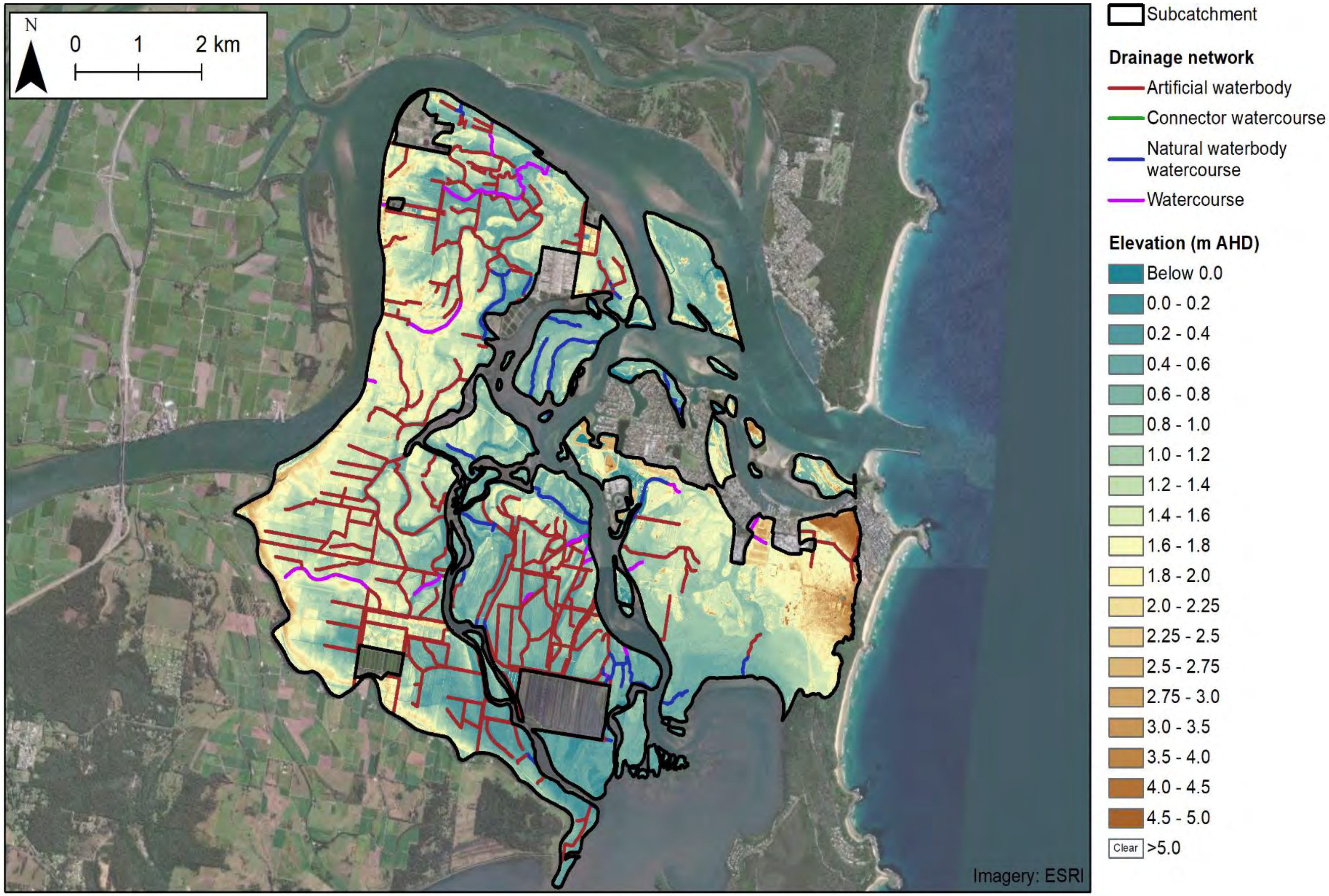

Figure 8-67: Palmers Island/Micalo Island/Yamba subcatchment elevation and drainage network

8.13.2 History of remediation

As discussed in Section 8.7.2, Palmers Channel (the western boundary of this subcatchment) was used as a demonstration site in the Clarence River for modifying floodgates to allow controlled tidal flushing in 2001 and 2002 (Davison and Wilson, 2003). Seven (7) CVC floodgates in this subcatchment have been modified with a buoyancy gate and lifting device, as part of the Clarence Floodplain Project (Figure 8-68). These gates promote tidal flushing and aquatic habitat without requiring active management from the local landholders. The tidal buffering helps to neutralise acidic discharges from ASS in the subcatchment. In addition, two (2) other floodgates have lifting devices (floodgate ID F-3170-FB-0001 and F-3500-FB-0001) and one (1) floodgate has a buoyancy gate (floodgate ID F-3250-FT-0006).

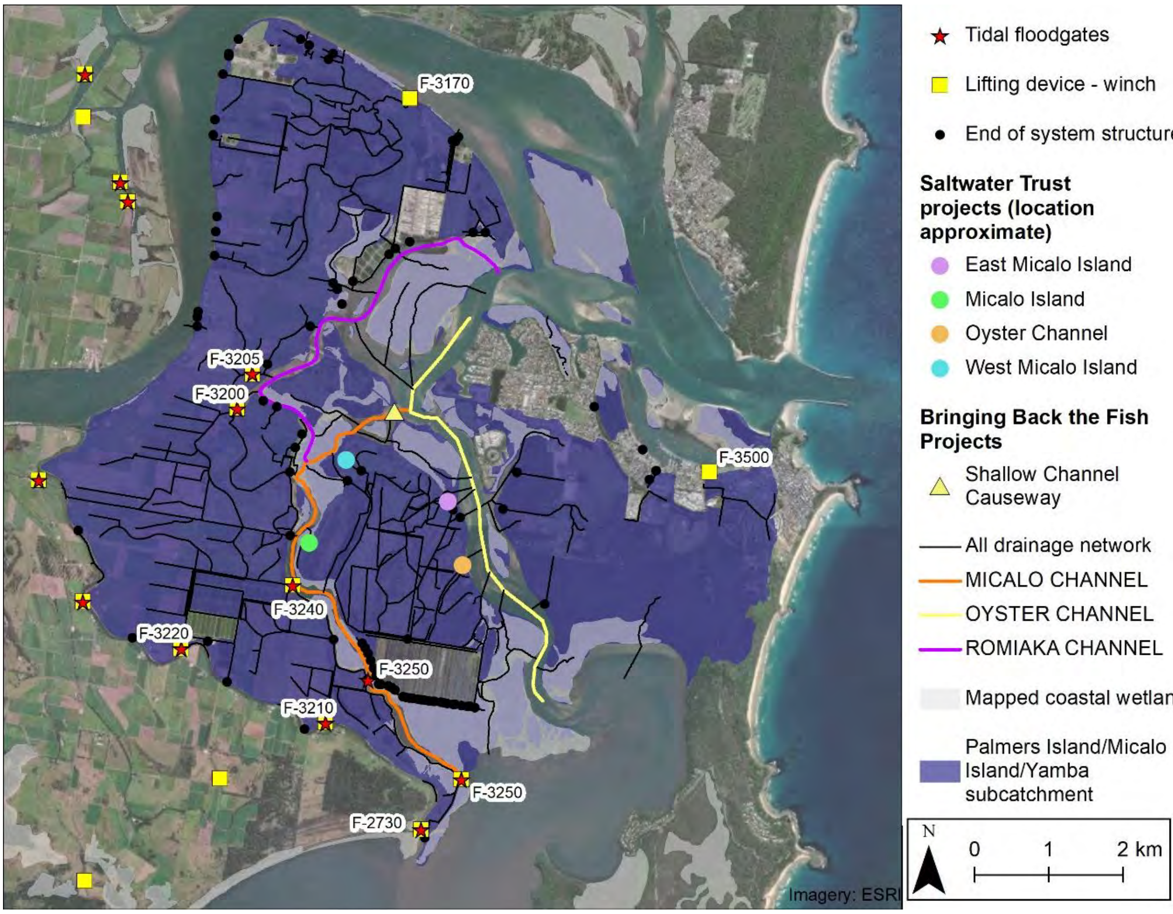

Figure 8-68: Palmers Island/Micalo Island/Yamba subcatchment including previous remediation actions

Micalo Island was also the focus of a number of remediation works funded by NSW Recreational Fishing Saltwater Trust Fund, supported by NSW DPI (NSW DPI, n.d.) between 2003 and 2005. Four (4) projects were funded on Micalo Island for private land holders to undertake work to improve aquatic habitat. The four projects included (NSW DPI, n.d.):

- West Micalo Island 2004/2005 – restored tidal flows to 50 ha of estuarine habitat through the installation of culverts under a causeway;

- Oyster Channel 2003/2004/2005 – restoration of tidal flows to 15 ha of wetland and opened 1.5 km for fish passage. Stock exclusion fencing was also installed, as well as planting of native vegetation;
- Micalo Island (south-west) 2003/2004/2005 – restored 25 ha of estuarine wetland habitat through floodgate removal, redesigning of levees, stock exclusion and construction of a fish friendly bridge crossing; and
- East Micalo Island 2004/2005 – installation of a tidal fish gate and improving connectivity underneath a causeway re-introduced tidal flows to 5 km of waterway and resulted in creation of saltmarsh.

In addition, as part of the "Bringing Back the Fish Project" (Industry and Investment NSW, 2009) a culvert was installed on the Shallow Channel Causeway (highlighted in Figure 8-68), which improved tidal flows and intertidal habitat to over 7 km of Micalo Channel. The project was completed in partnership between CVC, Northern Rivers Catchment Management Authority, WetlandCare Australia, and DECCW.

Sugar cane farms in the Clarence River floodplain operate in compliance with "The NSW sugar industry best practice guidelines for acid sulfate soils" (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the Palmers Island/Micalo Island/Yamba subcatchment were not obtained, cane farms typically implement the following ASS management actions:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.13.3 Floodplain drainage - sea level rise vulnerability

Figure 8-69 and Figure 8-70 (primary floodgates only) summarises the sea level rise vulnerability of the Palmers Island/Micalo Island/Yamba subcatchment. The assessment identified six (6) structures as 'Moderately vulnerable' in the near future, including primary floodgate F-3220-FP-0001. This increased to 27 structures in the far future, including all primary floodgates except structure F-3200-FP-0001. No structures were classified as 'Least vulnerable' in the far future.

Similarly, Figure 8-69 shows that an increasingly large portion of the subcatchment will be impacted by reduced drainage due to sea level rise. Large areas of Micalo Island (between Micalo Channel and Oyster Channel in Figure 8-68) will be at low risk under the near future sea level rise scenario. Under the far future sea level rise scenario, approximately a third of the subcatchment is classified as medium risk. Reduced drainage may impact agricultural land uses throughout the subcatchment. Due to the location in the lower estuary, high salinity levels may also impact agricultural productivity as sea level rise continues to occur.

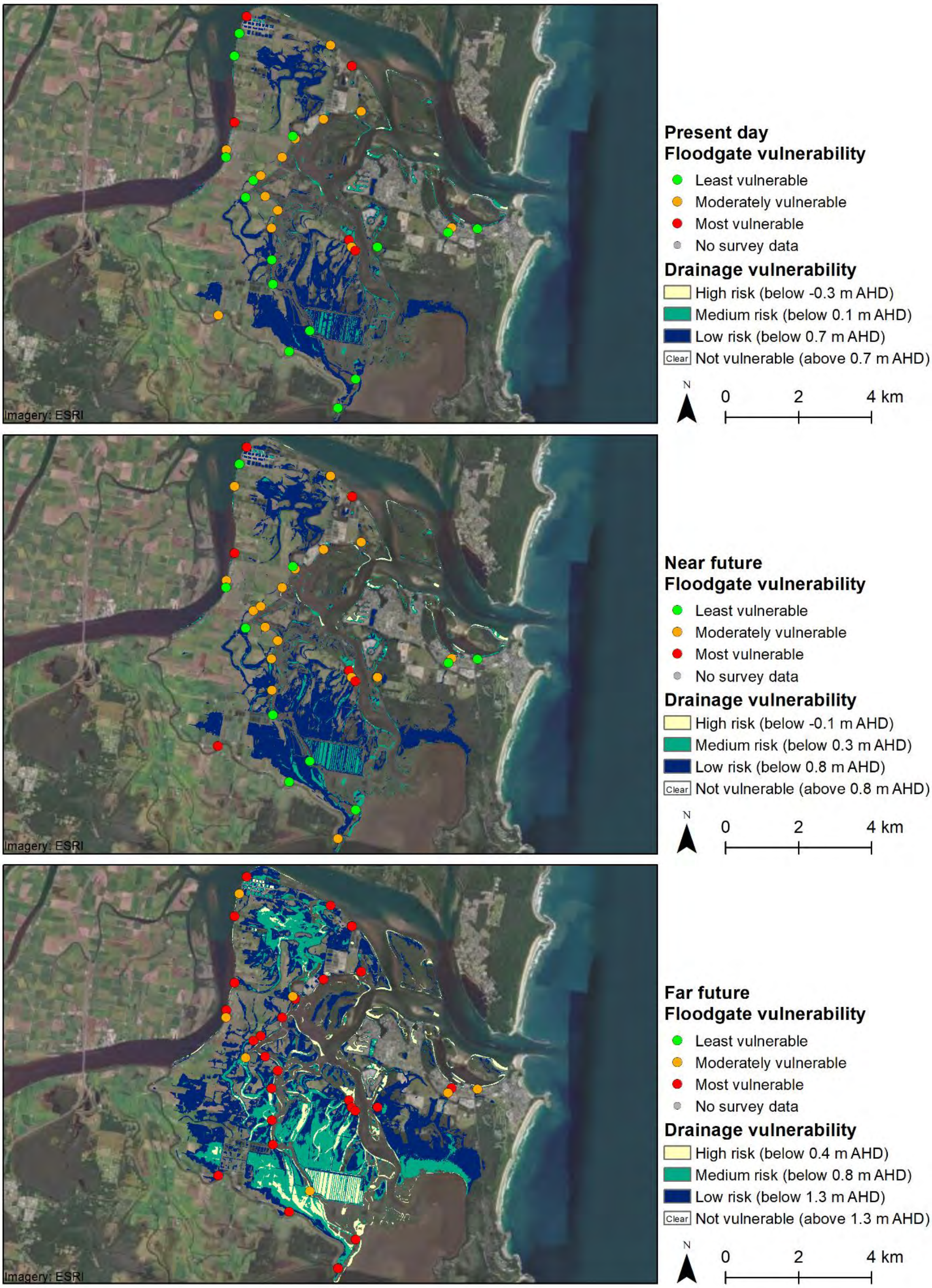

Figure 8-69: Sea level rise drainage vulnerability – Palmers Island/Micalo Island/Yamba subcatchment

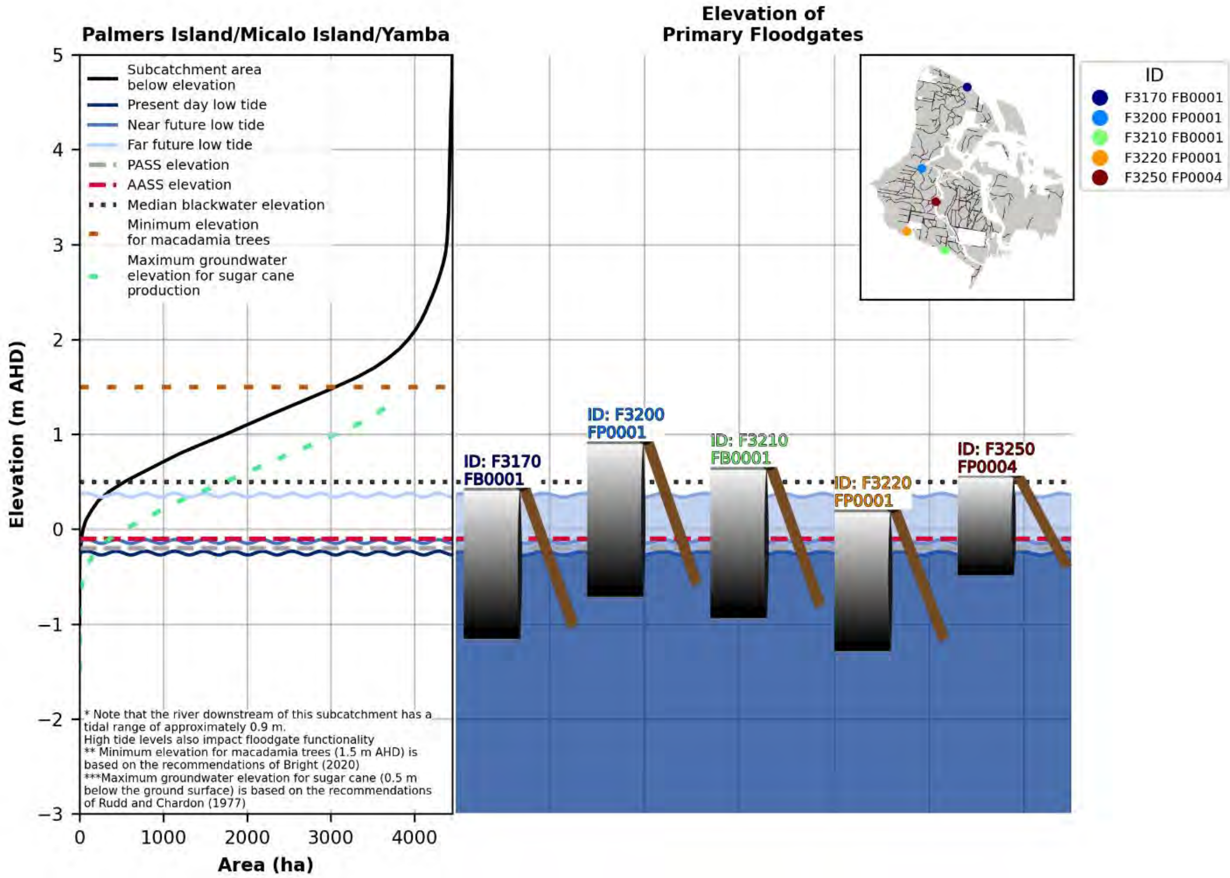

Figure 8-70: Primary floodgates and key floodplain elevations – Palmers Island/Micalo Island/Yamba subcatchment

8.13.4 Management options

Short-term management options

CVC has already modified a number of floodgates in the Palmers Island/Micalo Island/Yamba subcatchment to allow controlled tidal flushing. Modification of additional floodgates to promote tidal flushing should be encouraged, however due to the location in the lower estuary (and therefore high salinity levels) and the low lying nature of the subcatchment, opportunities for additional modifications may be limited without impacting current land uses.

As shown in Figure 8-68, there is a substantial area in this subcatchment that is mapped as Coastal Management SEPP coastal wetlands. Where this is on private property, local landholders should be encouraged and supported to actively manage the land to support environmental outcomes, such as stock exclusion from identified wetland areas.

Long-term management options

The Palmers Island/Micalo Island/Yamba subcatchment may be impacted by reduced drainage and increased salinity in the drainage system as sea level rise occurs. Where present day land uses are likely to be significantly impacted, natural estuarine hydrology could be actively restored through the removal of floodgates and infilling artificial drainage networks.

The Recreational Fishing Trust Saltwater Fund has funded four (4) projects on Micalo Island that successfully restored intertidal habitats. These projects should be expanded if the agricultural land uses on the adjacent land becomes less viable due to sea level rise. This may include improving connectivity through causeways, removing barriers to fish passage (e.g. floodgates) and infilling artificial drainage networks. Similar projects should also be encouraged on Palmers Island in low lying areas impacted by sea level rise. While this subcatchment is considered low-moderate risk of acid in the context of the wider Clarence River floodplain, some acidity (potential acidity) of the soils has been observed, particularly at elevations around 0 m AHD. Restoration of natural estuarine hydrology in low lying areas will prevent acidification of the soils, as well as reducing the blackwater risk by encouraging water tolerant vegetation.

A summary of the recommended management options for the Palmers Island/Micalo Island/Yamba subcatchment is provided in Table 8-18.

Table 8-18: Summary of management options for Palmers Island/Micalo Island/Yamba subcatchment

		Effectiveness at improving:		
Timeframe	**Strategy**	**Wetland habitat and fish passage**	**Impacts of ASS**	**Impacts of blackwater**
Short-term	Floodgate modifications	Moderate	Small	Negligible
Long-term	Localised restoration of estuarine wetlands	High	High	Moderate

8.14 South Grafton subcatchment

Acid priority rank:	**12**
Blackwater priority rank:	**11**
Infrastructure	
Approximate waterway length (km)	50
# Privately owned end of system structures	1
# Publicly owned end of system structures	50
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID)	F-1010-FB-0001, F-1020-FB-0001, F-1030-FB-0001, F-1050-FB-0002, F-1170-FB-0001, F-1190-FB-0001, F-1190-FP-0001, F-4020-FB-0001
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.3 to 0.6
Approximate AASS elevation (m AHD)	0
Approximate PASS elevation (m AHD)	-0.4
Median blackwater elevation (m AHD)	1.5
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	-0.1
Far future low level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	57.7
Saltmarsh (km)	30.8
Seagrass (km)	49.0
Mangroves (km)	14.4
Coastal Management SEPP coastal wetlands (km)	11.0
Land use	
Total floodplain area (ha)	1,810
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	1,327 (73%)
Classified as forestry (ha (%))	31 (2%)
Classified as sugar cane (ha (%))	5 (0%)
Classified as horticulture (ha (%))	1 (0%)
Classified as other cropping (ha (%))	1 (0%)
Classified as urban/industrial/services (ha (%))	149 (8%)
Classified as marsh/wetland (ha (%))	259 (14%)
Other (ha (%))	38 (2%)
Land values	
Estimated total primary production value ($/year)	$370,000
Average land value above 1.5 m AHD ($/ha)	$4,500
Average land value below 1.5 m AHD ($/ha)	$17,100

8.14.1 Site description

The South Grafton subcatchment is in the upper Clarence River floodplain, and the majority of the land (~75%) is used for grazing. The areas within the catchment identified as Crown land in Figure 8-71 is mostly leased for private grazing. The majority of the subcatchment is relatively high (above +2 m AHD), except for a small, low backswamp on the eastern side of the subcatchment, which is situated near +0.8 m AHD (shown in Figure 8-72). Some of the drainage infrastructure (including floodgates and flood mitigation drains) in this subcatchment also provide flood mitigation to South Grafton.

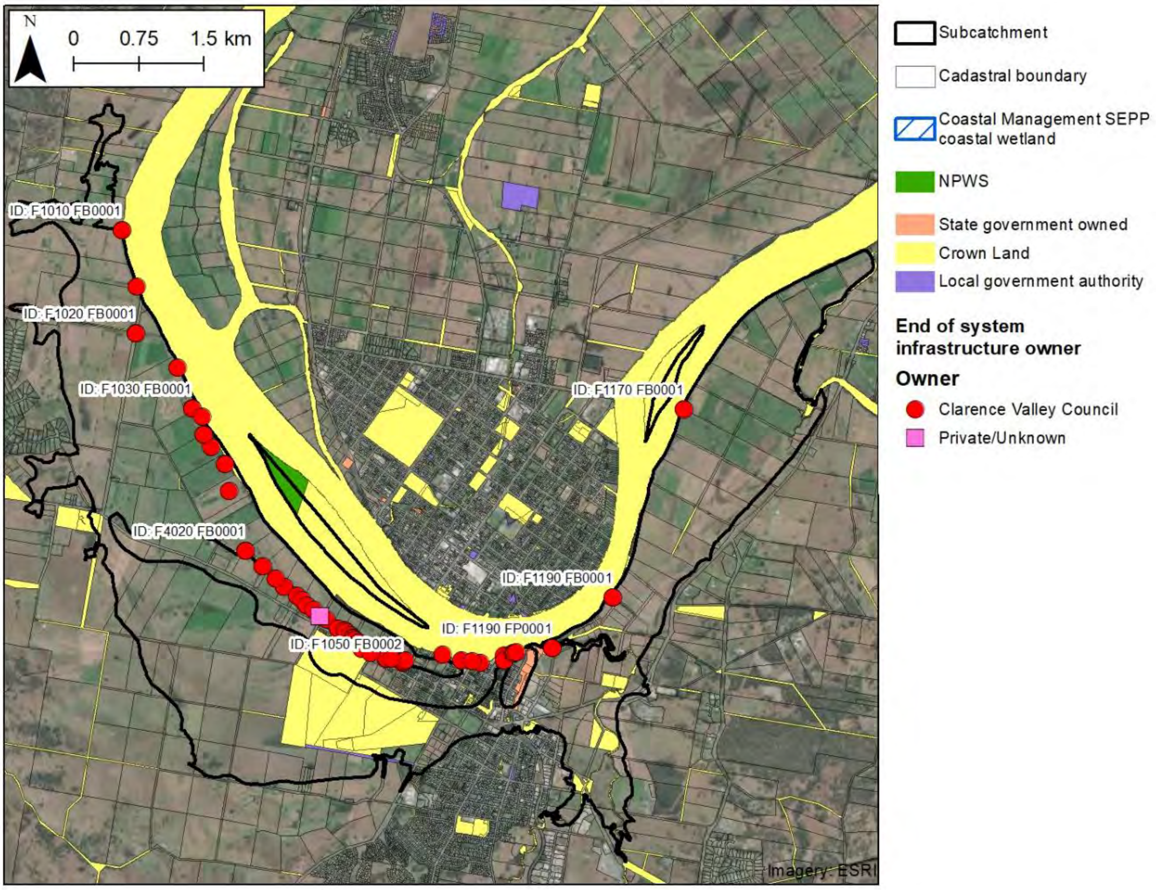

Figure 8-71: South Grafton subcatchment - land and end of system infrastructure tenure

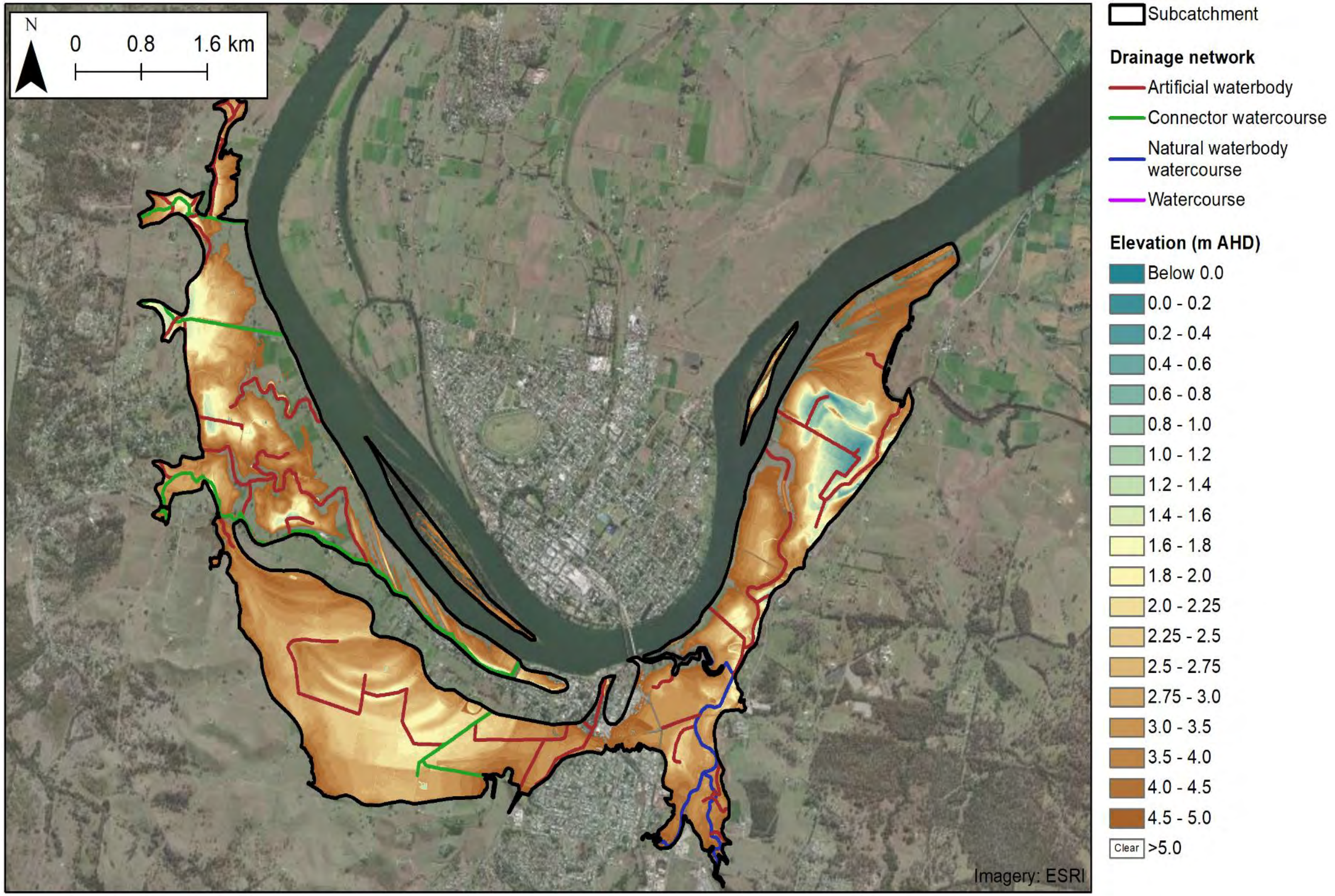

Figure 8-72: South Grafton subcatchment elevation and drainage network

8.14.2 History of remediation

CVC has modified a number of structures in the South Grafton subcatchment to improve water quality as shown in Figure 8-73. This includes:

- Lifting devices that allows floodgates to be opened periodically, installed on three (3) floodgates (floodgate ID F-1170-FB-0001, F-4140-FB-0003 and F-1020-FB-0001); and
- Two (2) floodgates have been fitted with auto-tidal buoyancy gates (floodgate ID F-1190-FT-0001 and F-1060-FT-0001). This allows fish passage and promotes improved water quality through increased flushing.

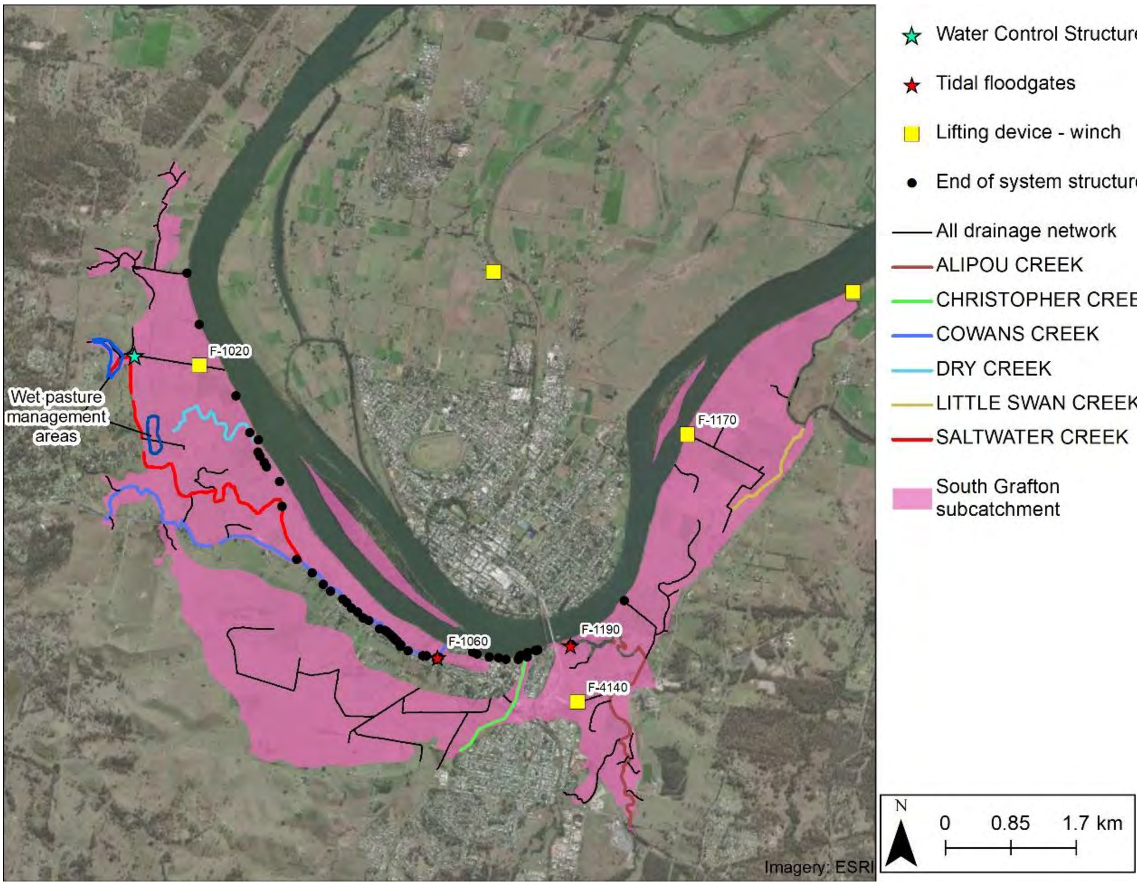

Figure 8-73: South Grafton subcatchment including previous remediation actions

As part of the Clarence Floodplain Project, the Waterview Freeman Drain (upstream of floodgate F- 1020) was targeted for improvements. Funding was secured from the NSW Environmental Trust Urban Sustainability Program in 2009 to install two (2) water control structures which allows for wet pasture management (i.e. a small freshwater wetland) (Clarence Valley Council, 2009).

8.14.3 Floodplain drainage - sea level rise vulnerability

The vulnerability of the floodplain and floodplain infrastructure to sea level rise in the South Grafton floodplain is shown in Figure 8-74. The majority of the floodplain is relatively high, with the exception of a small backswamp on the western extent of the subcatchment, which may experience reduced drainage as sea level rise occurs in the future. Seven (7) of the 43 floodgates with survey information have been classified as 'Moderately vulnerable' under the far future sea level rise scenario, including primary floodgates F-1010-FB-0001, F1020-FB0001, F1190-FB-0001, F1190-FP-0001. The elevation of primary floodgates compared to key elevations across the subcatchments is shown in Figure 8-75. Reduced drainage through this infrastructure may also impact flood mitigation capacity in this area.

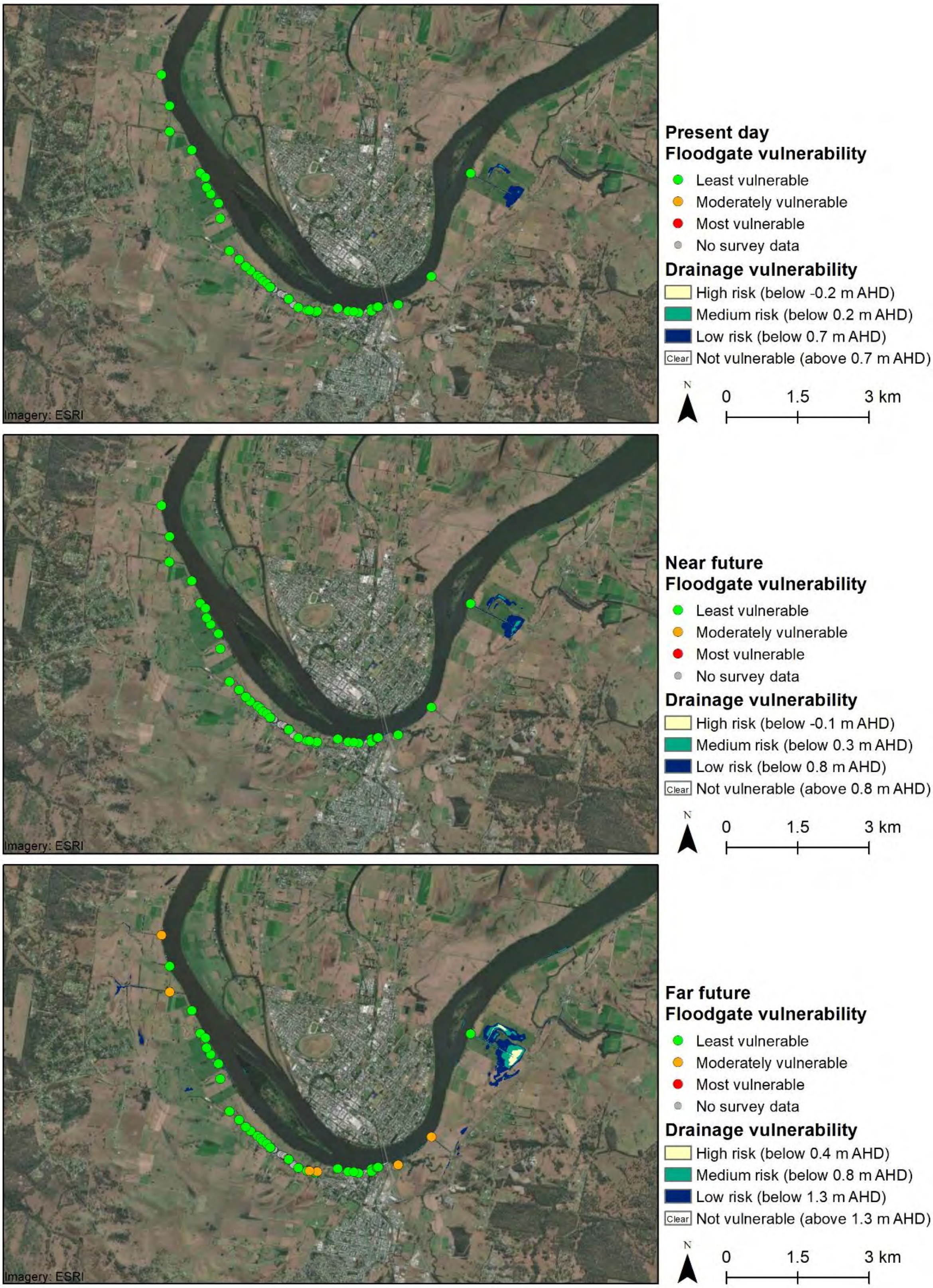

Figure 8-74: Sea level rise drainage vulnerability – South Grafton subcatchment

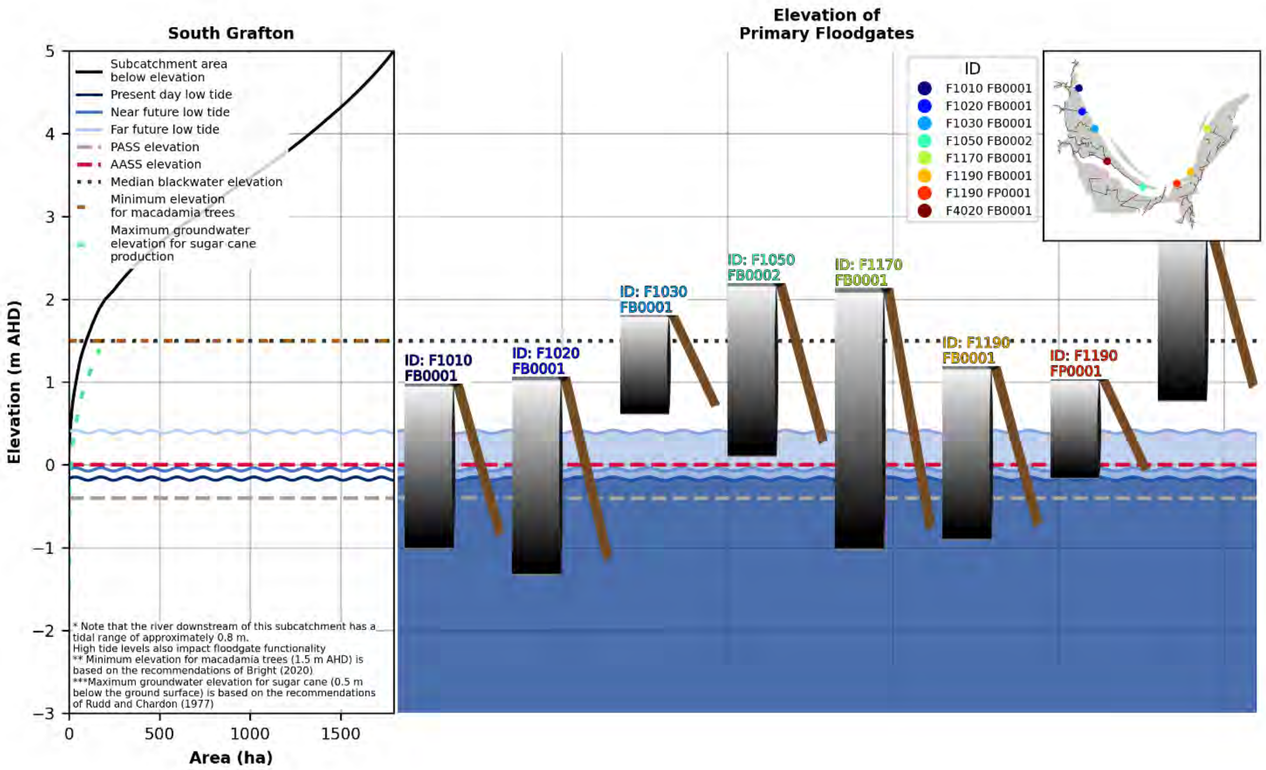

Figure 8-75: Primary floodgates and key floodplain elevations – South Grafton subcatchment

8.14.4 Management options

Short-term management options

As shown in Figure 8-73, a number of the end-of-system floodgate structures in South Grafton have been modified with winches. The management of these gates should be reviewed to optimise the degree of tidal flushing and connectivity with the Clarence River. While limited acidity was observed in this subcatchment (soil pH was above 5.7 in all three (3) available profiles), improved connectivity with the Clarence River would:

- Improve overall water quality in the drainage system through increased flushing; and
- Open additional areas for aquatic habitat and fish passage.

Note that salinity levels at in the Clarence River estuary at Grafton are generally fresh, except during prolonged dry periods when low catchment inflows result in saline ingress to the upper estuary to salinity levels of approximately 5 to 10 ppt (Manly Hydraulics Laboratory, 2016).

Long-term management options

The low backswamp areas in this subcatchment are likely to be affected by reduced drainage due to future sea level rise. While the area is small, the drainage system could be reshaped (or a rock sill could be installed) to restore natural freshwater hydrology in low lying areas. This would encourage water tolerant vegetation which would reduce the risk of blackwater generation from this area, however weeds may require ongoing management. Note that any changes in hydrology will require extensive studies into the potential impacts to flooding and land uses, and should only be implemented with extensive consultation of local landholders and consideration of the social and economic impacts of such changes. Active management of floodgate infrastructure should continue long-term.

A summary of the recommended management options for the South Grafton subcatchment is provided in Table 8-19.

Table 8-19: Summary of management options for South Grafton

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	Impacts of ASS	Impacts of blackwater
Short-term	Floodgate modifications	Moderate	Small	Negligible
Long-term	Localised restoration of natural freshwater backswamp hydrology	None	Small	Small

8.15 West Woodford Island subcatchment

Acid priority rank:	**13**
Blackwater priority rank:	**6**
Infrastructure	
Approximate waterway length (km)	125
# Privately owned end of system structures	3
# Publicly owned end of system structures	17
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID)	F-1890-FB-0001, F-1900-FP-0001, F-2380-FB-0001, F-2400-FB-0001
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1.5 to -0.4
Approximate AASS elevation (m AHD)	N/A
Approximate PASS elevation (m AHD)	1.8
Median blackwater elevation (m AHD)	1.6
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0.0
Far future low level (m AHD)	0.5
Proximity to sensitive receivers	
Oyster leases (km)	24.5
Saltmarsh (km)	0.6
Seagrass (km)	15.7
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	3,835
Classified as conservation and minimal use (ha (%))	34 (1%)
Classified as grazing (ha (%))	1,039 (27%)
Classified as forestry (ha (%))	26 (1%)
Classified as sugar cane (ha (%))	1,983 (52%)
Classified as horticulture (ha (%))	3 (0%)
Classified as other cropping (ha (%))	192 (5%)
Classified as urban/industrial/services (ha (%))	183 (5%)
Classified as marsh/wetland (ha (%))	225 (6%)
Other (ha (%))	149 (4%)
Land values	
Estimated total primary production value ($/year)	$6,400,000
Average land value above 1.6 m AHD ($/ha)	$10,300
Average land value below 1.6 m AHD ($/ha)	$7,600

8.15.1 Site description

The West Woodford Island subcatchment is located in the mid-estuary of the Clarence River and is mostly used for growing sugar cane (Figure 8-76). Grazing also occurs in the low areas of the subcatchment where sugar cane is less viable. As shown in Figure 8-77, the subcatchment has an extensive drainage system, with a total length of around 125 km. While there is a network of natural watercourses, major flood mitigation works were completed in the 1960s to reduce flood impacts, and artificial drainage networks have been constructed to facilitate agricultural production throughout the subcatchment.

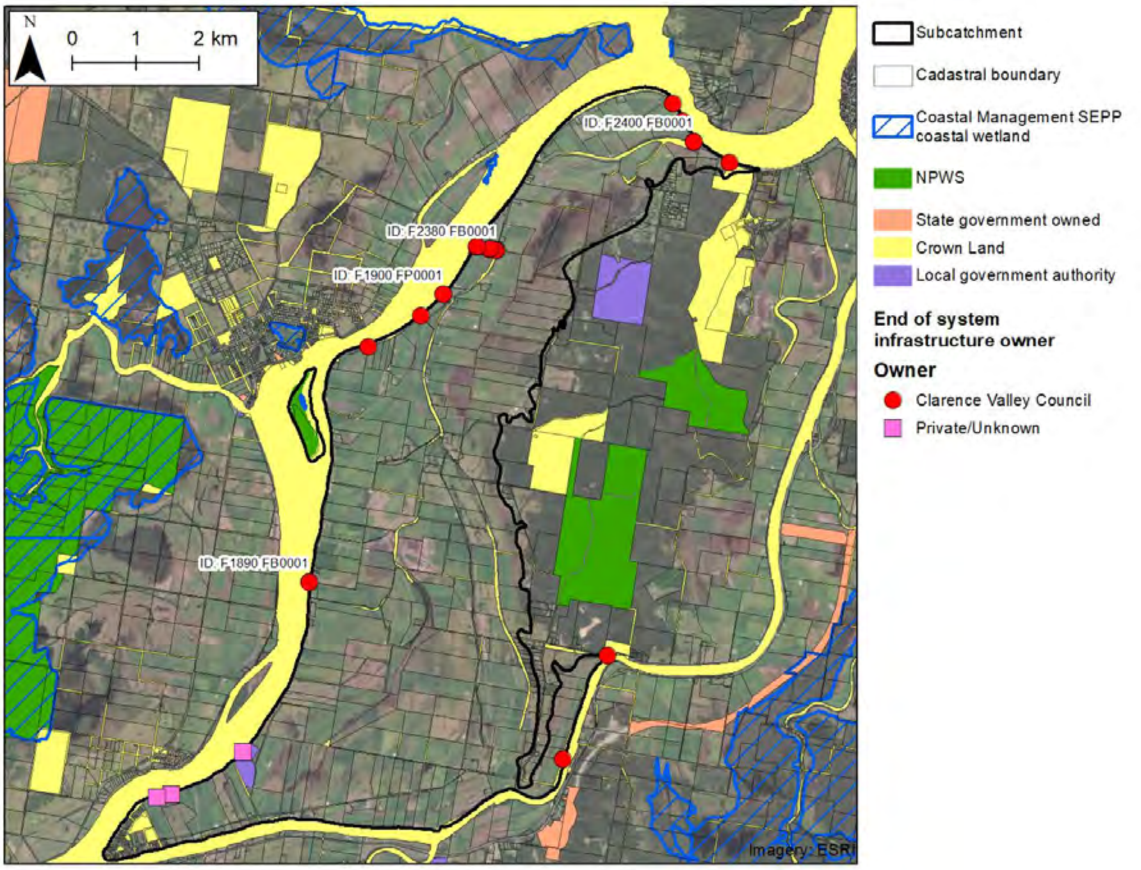

Figure 8-76: West Woodford Island subcatchment - land and end of system infrastructure tenure

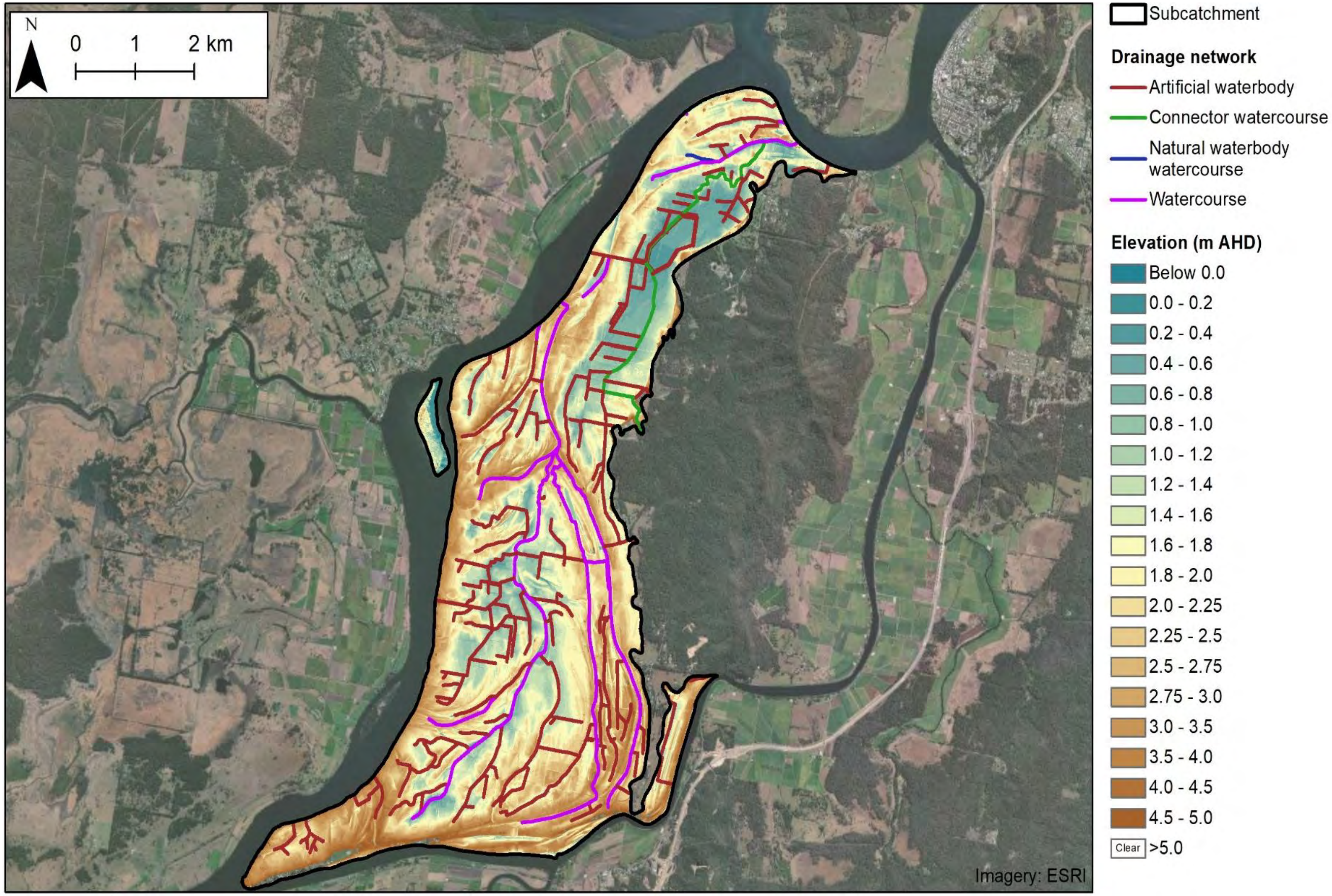

Figure 8-77: West Woodford Island subcatchment elevation and drainage network

8.15.2 History of remediation

CVC has modified at least six (6) floodgates in the West Woodford Island subcatchment, highlighted in Figure 8-78. These include:

- Three (3) floodgates on the western side of the subcatchment have been fitted with lifting devices which allow them to be selectively opened (floodgate ID F-2380-FB-0001, F-1900-FP-0001 and F-1890-FB-0001);
- Two (2) floodgates that have been fitted with auto-tidal floodgates and lifting devices (floodgate ID F-2385-FT-0001 and F-2395-FT-0001); and
- One (1) floodgate which has been fitted with an auto-tidal buoyancy gate on Poverty Creek (floodgate ID F-2400-FT-0001).

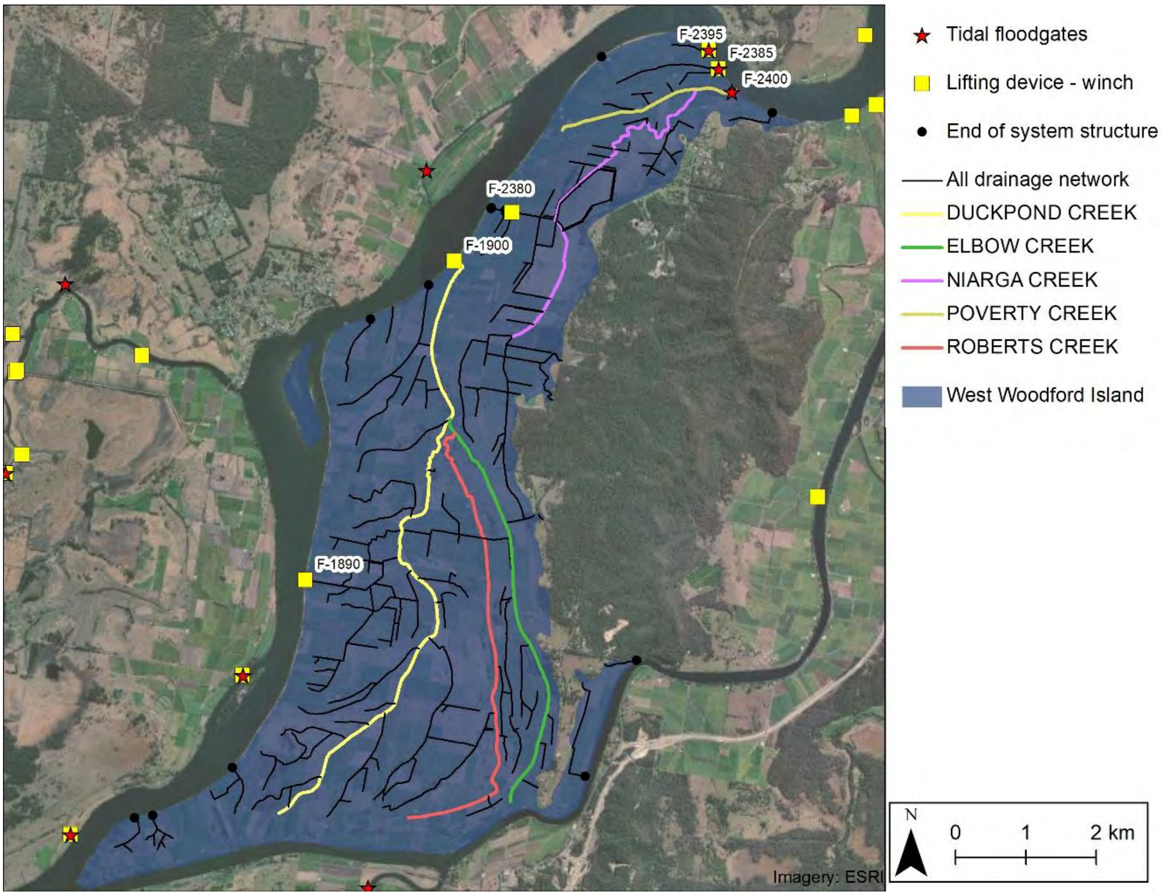

Figure 8-78: West Woodford Island subcatchment including previous remediation actions

Floodgate ID F-2400-FT-0001 shown in Figure 8-79 was part of a significant remediation project of Poverty Creek. Poverty Creek was completely disconnected from the Clarence River by an earth bund as part of flood mitigation works in the 1960s, which prevented fish passage and resulted in stagnant water prone to algal blooms (Clarence Valley Council, n.d.). The remediation works implemented by CVC required a new channel and culvert to be installed, as well as modifications to upstream floodgates to manage impacts to land holders.

Figure 8-79: Secondary floodgate with buoyancy gate at floodgate ID F-2400-FT on Poverty Creek

Sugar cane farms in the Clarence River floodplain operate in compliance with “The NSW sugar industry best practice guidelines for acid sulfate soils” (Sunshine Sugar, 2020). While details of specific drainage management on cane farms in the West Woodford Island subcatchment were not obtained, cane farms typically implement the following ASS management actions:

- Laser level farms to reduce the drainage density required to allow surface water drainage;
- Construct new drainage works that are designed to minimise the interaction with acidic soils; and
- Complete extensive liming.

8.15.3 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability of the West Woodford Island subcatchment is summarised in Figure 8-80. The low area around Niarga Creek is the most vulnerable section of the floodplain, and is largely classified as medium risk under the far future sea level rise scenario (0.8 m AHD). This area may become increasingly difficult to drain as sea levels continue to rise. Localised areas to the west of Poverty Creek may also be impacted by reduced drainage which may impact present day land uses.

The vulnerability assessment identified one secondary structure, floodgate F-2380-FP-0001, as ‘Most vulnerable’ in the near future. The number of ‘Most vulnerable’ floodgates increased to three (3) in the far future scenario, including primary structure F-1890-FB-0001 and secondary structure F-2380-FP-0002. All other primary structures are classified as ‘Moderately vulnerable’ in the far future. As shown in Figure 8-81, floodgate F-1890-FB-0001 is substantially lower than the other primary floodgates in the subcatchment. Reduced drainage efficiency of this floodgate may impact land uses upstream.

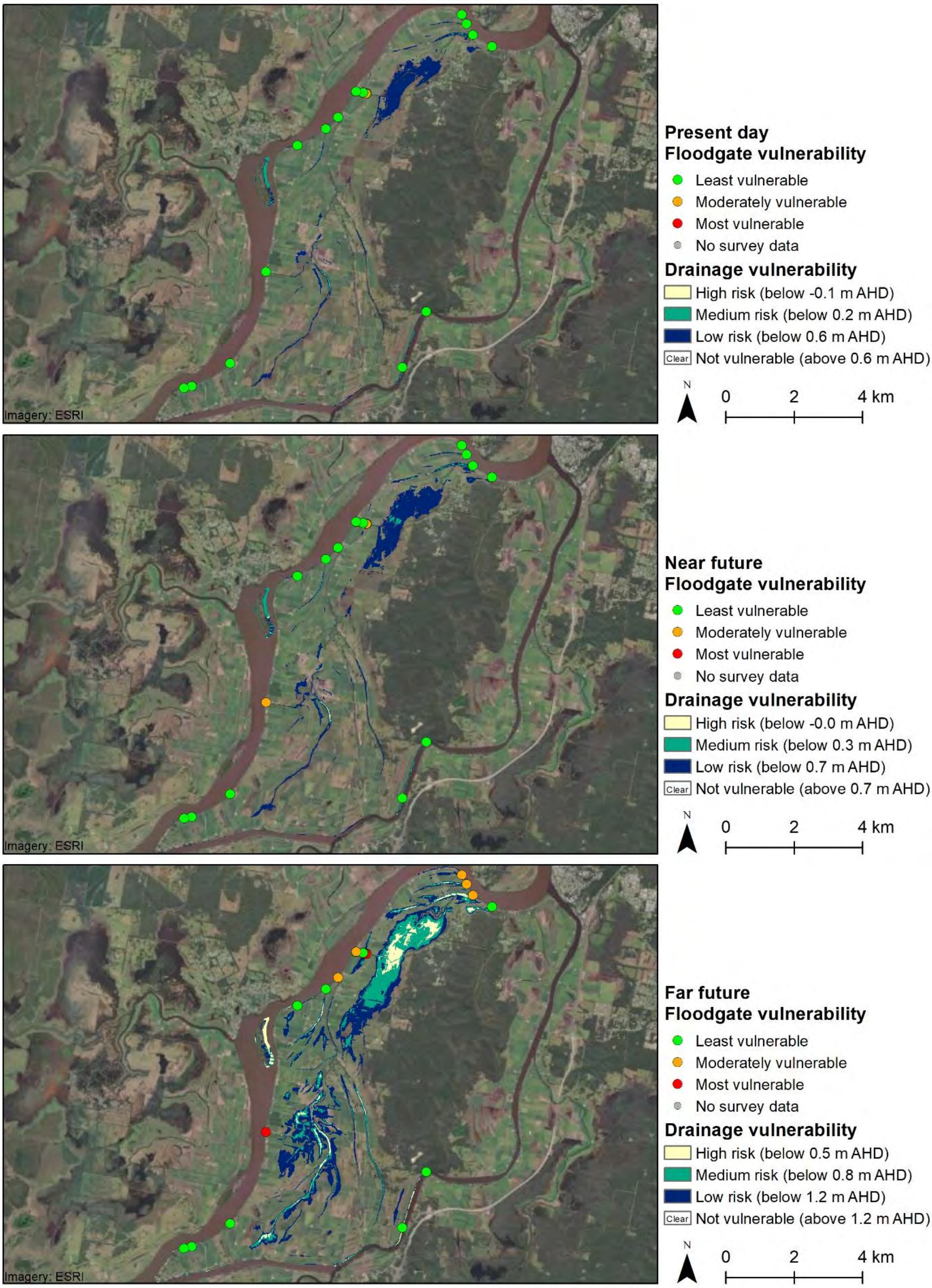

Figure 8-80: Sea level rise drainage vulnerability – West Woodford Island subcatchment

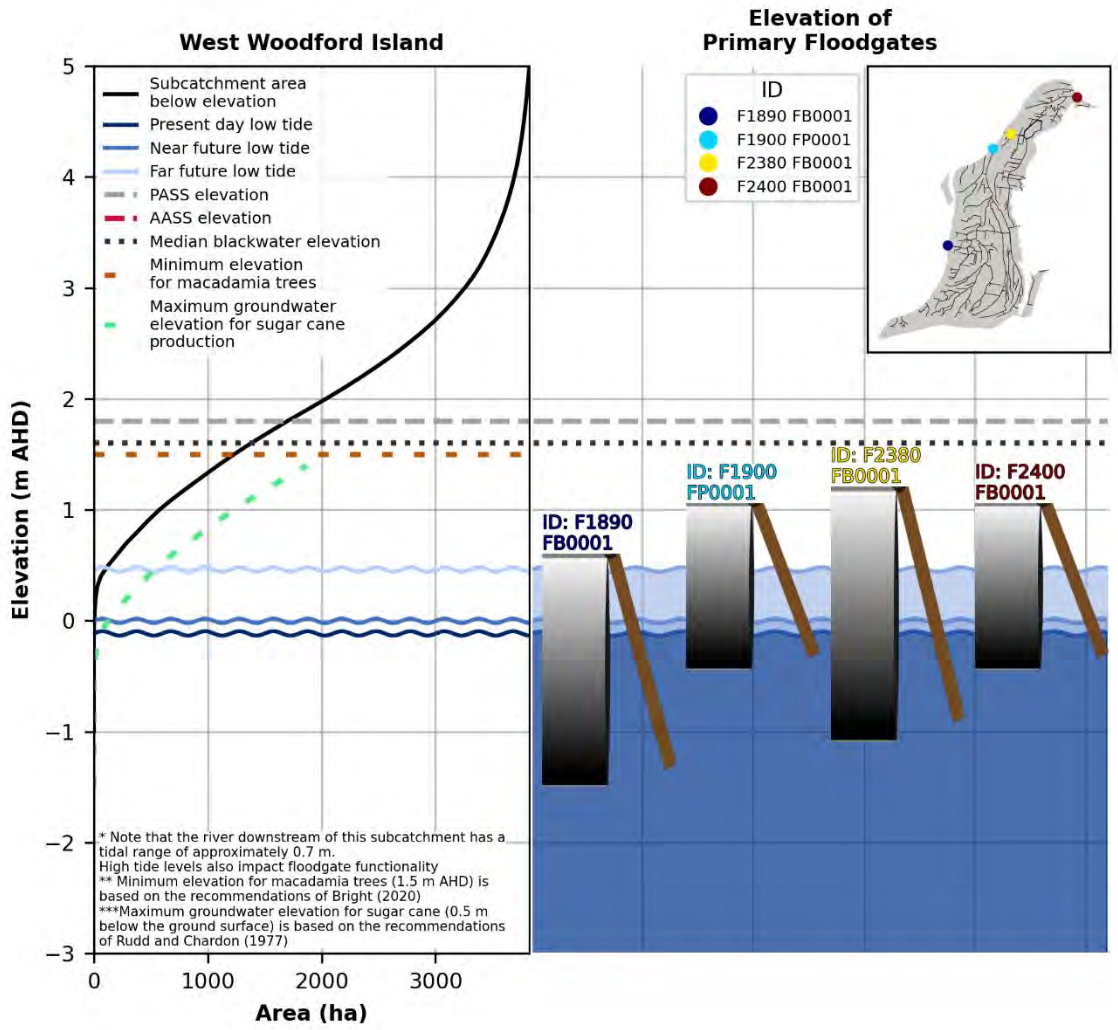

Figure 8-81: Primary floodgates and key floodplain elevations – West Woodford Island subcatchment

8.15.4 Management options

Short-term management options

Blackwater was observed to be discharging out of this subcatchment in February 2020 after a large rainfall event, shown in Figure 8-82. This is likely to be draining from the low lying grazing area near Niagra Creek, which was observed to be inundated two (2) days prior. It is recommended that wet management be encouraged in the grazing areas to stimulate water tolerant vegetation and reduce the risk of blackwater generation. This could be achieved through the installation of dropboard weirs in secondary drainage channels or infilling/reshaping of secondary floodplain drainage. Any plans for wet pasture management would require the cooperation and input from local landholders to ensure the resulting pasture is appropriate for their stock or needs.

Figure 8-82: Blackwater discharging from floodgate ID F-2380-FB-0001, 29 February 2020 (Photo: T. Tucker/WRL)

Long-term management options

In the longer term, the present day land uses of the low areas in this subcatchment may be impacted by reduced drainage under sea level rise. If agricultural uses of the land are no longer viable, the lowest areas should be targeted for restoration of natural freshwater hydrology. To achieve this reshaping or infilling of major drainage to reduce the efficient drainage of the backswamp areas and promote water retention should be considered. Changes to drainage may result in more prolonged inundation of the low-lying areas, while still providing adequate drainage to adjacent land in higher areas. Note that any changes in hydrology will require additional investigation into the potential impacts to flooding and land uses and should only be implemented with extensive consultation of local landholders and consideration of the social and economic impacts of such changes.

A summary of the recommended management options for the West Woodford Island subcatchment is provided in Table 8-20.

Table 8-20: Summary of management options for West Woodford Island

Timeframe	Strategy	Effectiveness at improving:		
		Wetland habitat and fish passage	**Impacts of ASS**	**Impacts of blackwater**
Short-term	Wet pasture management	None	Moderate	Moderate
Long-term	Rehabilitation of backswamp area	None	High	High

8.16 Alumy Creek subcatchment

Acid priority rank:	**14**
Blackwater priority rank:	**7**
<u>Infrastructure</u>	
Approximate waterway length (km)	86
# Privately owned end of system structures	2
# Publicly owned end of system structures	114
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	F-1110-FB-0001, F-1220-FB-0001, F-1230-FB-0001
<u>Elevations</u>	
Invert of primary floodplain infrastructure (m AHD)	-0.9 to -0.2
Approximate AASS elevation (m AHD)	2.6
Approximate PASS elevation (m AHD)	-0.9
Median blackwater elevation (m AHD)	2.1
Present day low water level (m AHD)	-0.2
Near future low water level (m AHD)	0.0
Far future low level (m AHD)	0.4
<u>Proximity to sensitive receivers</u>	
Oyster leases (km)	52.4
Saltmarsh (km)	25.4
Seagrass (km)	43.6
Mangroves (km)	9.0
Coastal Management SEPP coastal wetlands (km)	8.1
<u>Land use</u>	
Total floodplain area (ha)	3,977
Classified as conservation and minimal use (ha (%))	2 (0%)
Classified as grazing (ha (%))	2,845 (72%)
Classified as forestry (ha (%))	42 (1%)
Classified as sugar cane (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	38 (1%)
Classified as urban/industrial/services (ha (%))	551 (14%)
Classified as marsh/wetland (ha (%))	399 (10%)
Other (ha (%))	100 (3%)
<u>Land values</u>	
Estimated total primary production value ($/year)	$700,000
Average land value above 2.1 m AHD ($/ha)	$8,200
Average land value below 2.1 m AHD ($/ha)	$7,400

8.16.1 Site description

The Alumy Creek subcatchment includes the regional centre of Grafton and is located at the western extent of the Clarence River floodplain. The Alumy Creek subcatchment has been highly modified to assist with flood mitigation. A brief history of flood mitigation and drainage works includes (Woodhouse, 2001b):

- The first levees were constructed in the 1890's after a series of floods;
- 1965 – a pump was installed to extract saltwater from Alumy Creek that was used for irrigation;
- Also in 1965, the natural eastern confluence of Alumy Creek with the Clarence River was blocked with a pipe and culvert to prevent salinity from entering Alumy Creek. A series of artificial drains (also fitted with floodgates) were also constructed;
- 1966 to 1967 – the western confluence of Alumy Creek (in Grafton at Alice St) was also floodgated.
- 1965 to 1971 - Levees were also constructed to protect from flood impacts;
- In 1968, an inflatable Fabridam was placed at the end of Southgate Creek to retain water, support irrigation and prevent saline intrusion;
- 1975 – CRCC connected Alumy Creek to Southgate Creek and an earth wall was built to permanently close the natural eastern confluence with the Clarence River. This was intended to improve flow efficiency of Alumy Creek; and
- 1982 – the fabridam was replaced with a culvert under a concrete weir at the end of Southgate Creek called the Alumy Creek.

The present day Alumy Creek structure is shown in Figure 8-83 and consists of four (4) sluice gates that can be removed to allow tidal inflows into the Creek.

Figure 8-83: Alumy Creek Weir on Southgate Creek (sluice gates in place)

The Grafton township includes a large number of small lots on the south-western section of the subcatchment (Figure 8-84). The majority of the rest of the subcatchment is used for grazing (72% of the area). This includes a large, low area to the east of Grafton (shown in Figure 8-85) that is drained mostly through two (2) large artificial drains that discharge directly into the Clarence River. (Woodhouse, 2001b) stated the upstream sections of Alumy Creek were observed to be affected by acid sulfate soils to a greater degree than the downstream agricultural areas, and low dissolved oxygen levels were measured across the creek. The Alumy Creek area was also identified as an ASS hotspot by Tulau (1999a), noting fish kills had occurred due to acidic discharges.

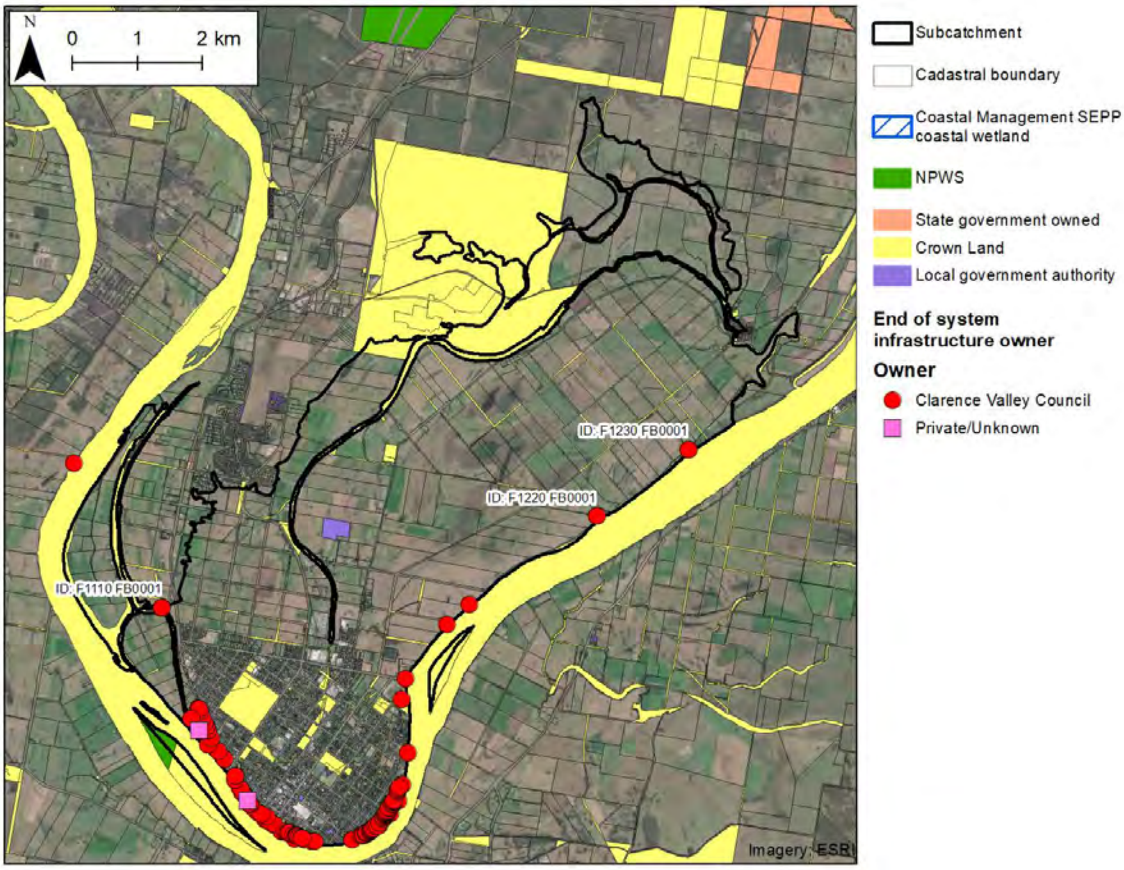

Figure 8-84: Alumy Creek subcatchment - land and end of system infrastructure tenure

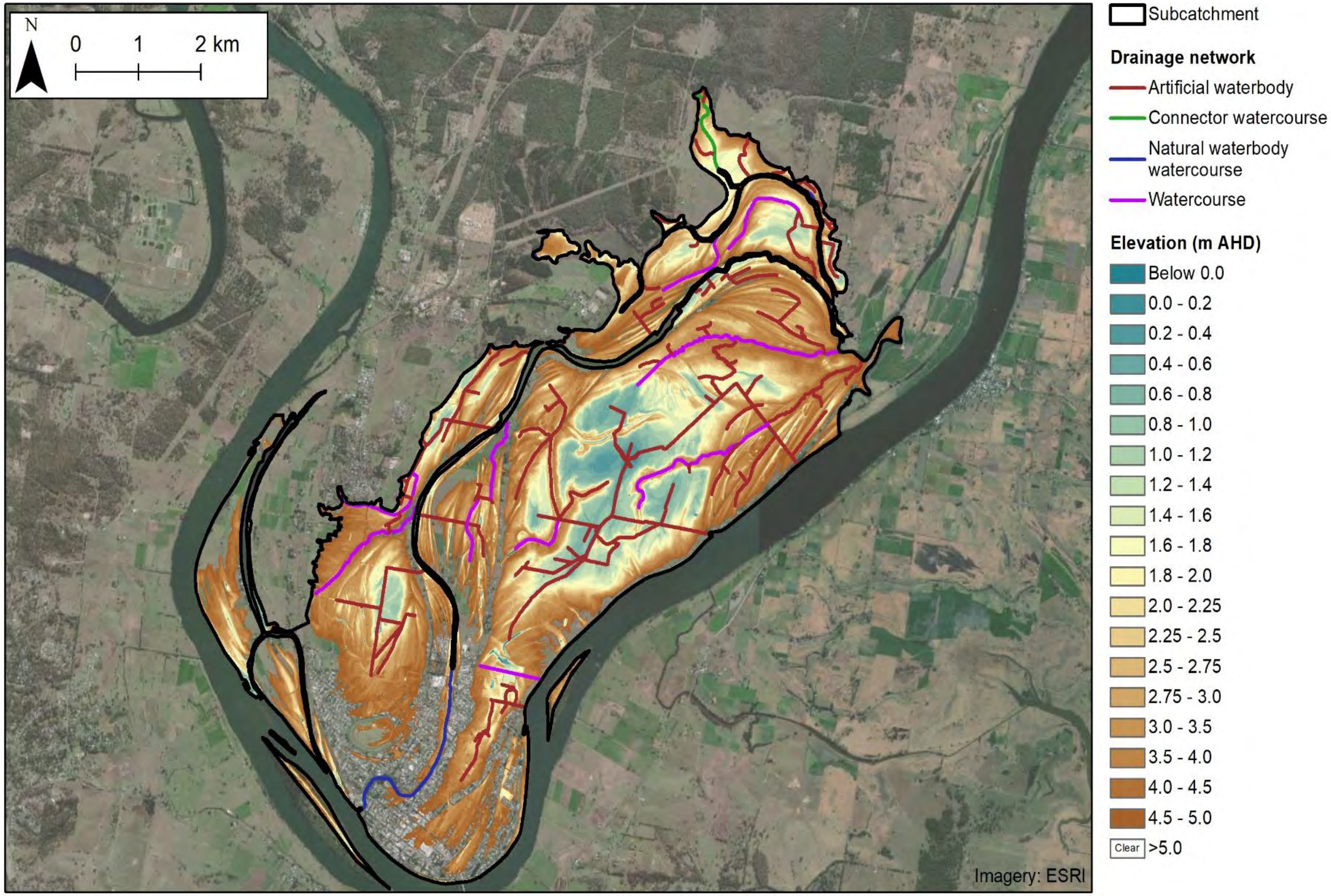

Figure 8-85: Alumy Creek subcatchment elevation and drainage network

8.16.2 History of remediation

The Alumy Creek Weir is the major piece of infrastructure that controls drainage in the Alumy Creek subcatchment (while the structure is physically located in the adjacent Southgate subcatchment, it is considered in this subcatchment as it is a major drainage flow path from the west). The Alumy Creek Weir was surveyed to have an elevation of approximately +1.1 m AHD, although there are also four (4) sluices in the weir that can be removed to re-introduce tidal flushing (as discussed in Section 8.17.1). While it is known the weir was opened in 2002 and 2003 (Clarence Valley Council, 2003) to manage acidity in Alumy Creek, however the current management of the sluice gates is unknown. Clarence Valley Council (2003) states that fish gates were being considered for the Alumy Creek Weir, however fish gates were not observed during field investigations completed for this study.

Two (2) floodgates within the Alumy Creek subcatchment have also been modified with lifting devices. The management of these gates is not known. Refer to Figure 8-86.

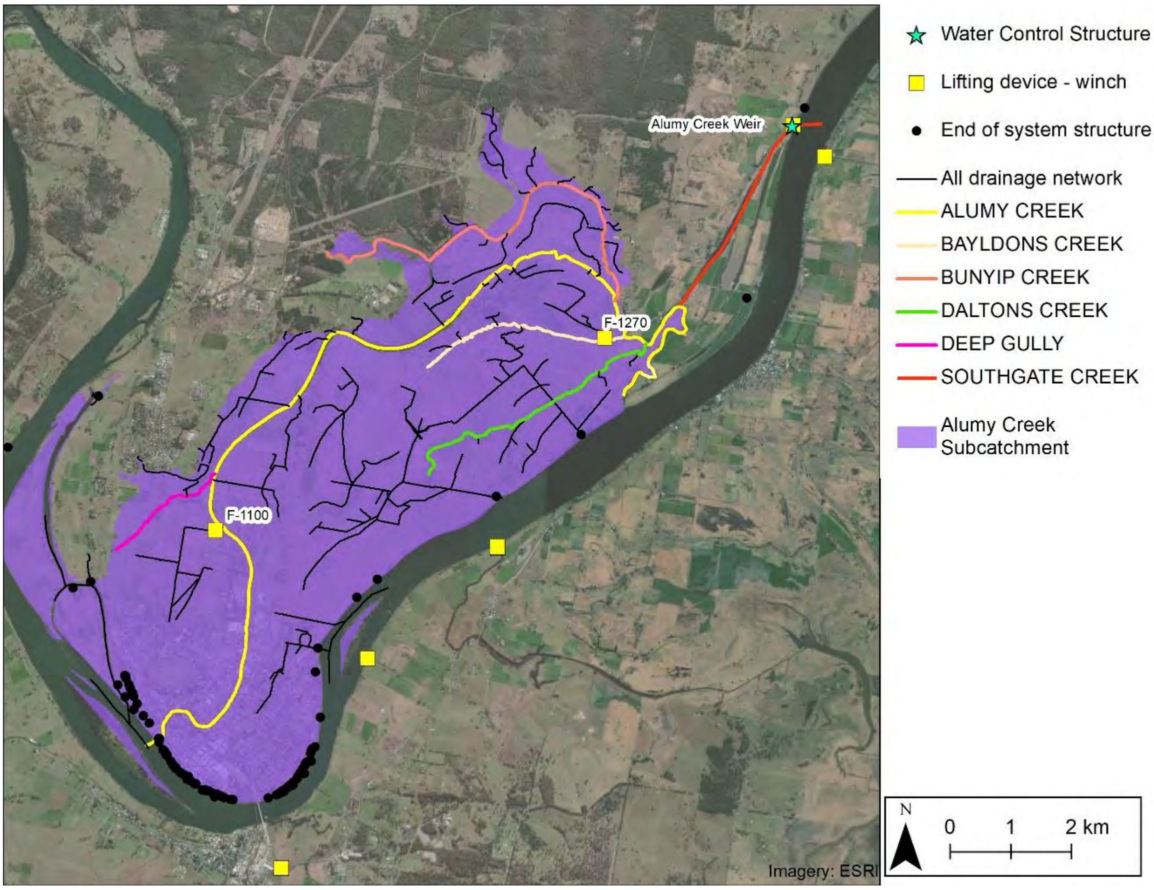

Figure 8-86: Alumy Creek subcatchment including previous remediation actions

8.16.3 Floodplain drainage - sea level rise vulnerability

Figure 8-87 summarises the vulnerability of the Alumy Creek subcatchment to sea level rise. The lowest area, on the eastern side of the subcatchment, may be impacted by reduced drainage under the far future sea level rise scenario. The greater Alumy Creek subcatchment , including the primary floodgates (see Figure 8-88) is relatively high and is unlikely to be significantly affected by reduced drainage due to sea level rise. However five (5) structures were classified as ‘Moderately vulnerable’ in the far future, including primary floodgate F-1110-FB-0001.

Note that this assessment does not consider changes in design event flooding due to sea level rise, which may have implications for the drainage management in the Alumy Creek subcatchment.

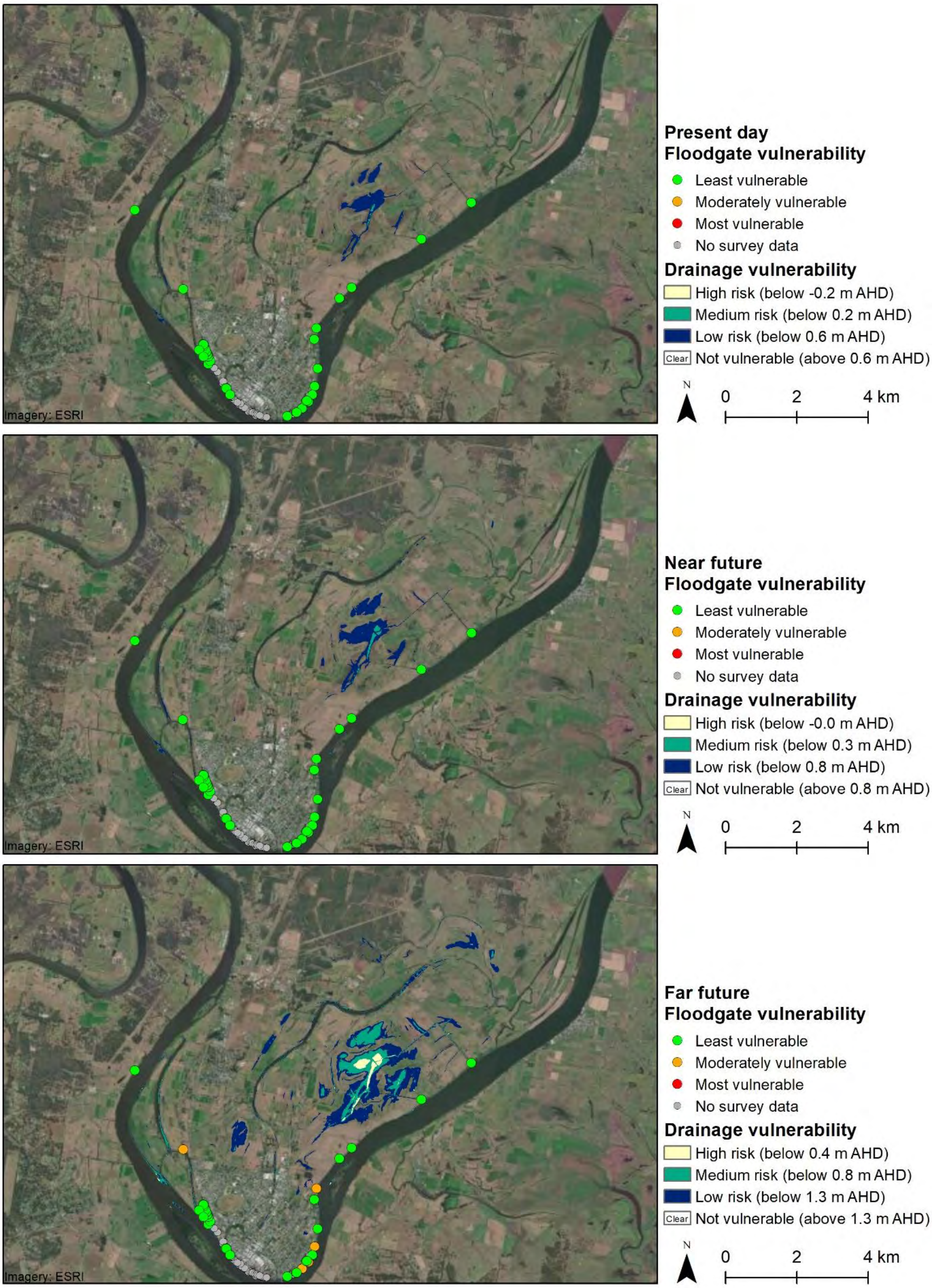

Figure 8-87: Sea level rise drainage vulnerability – Alumy Creek subcatchment

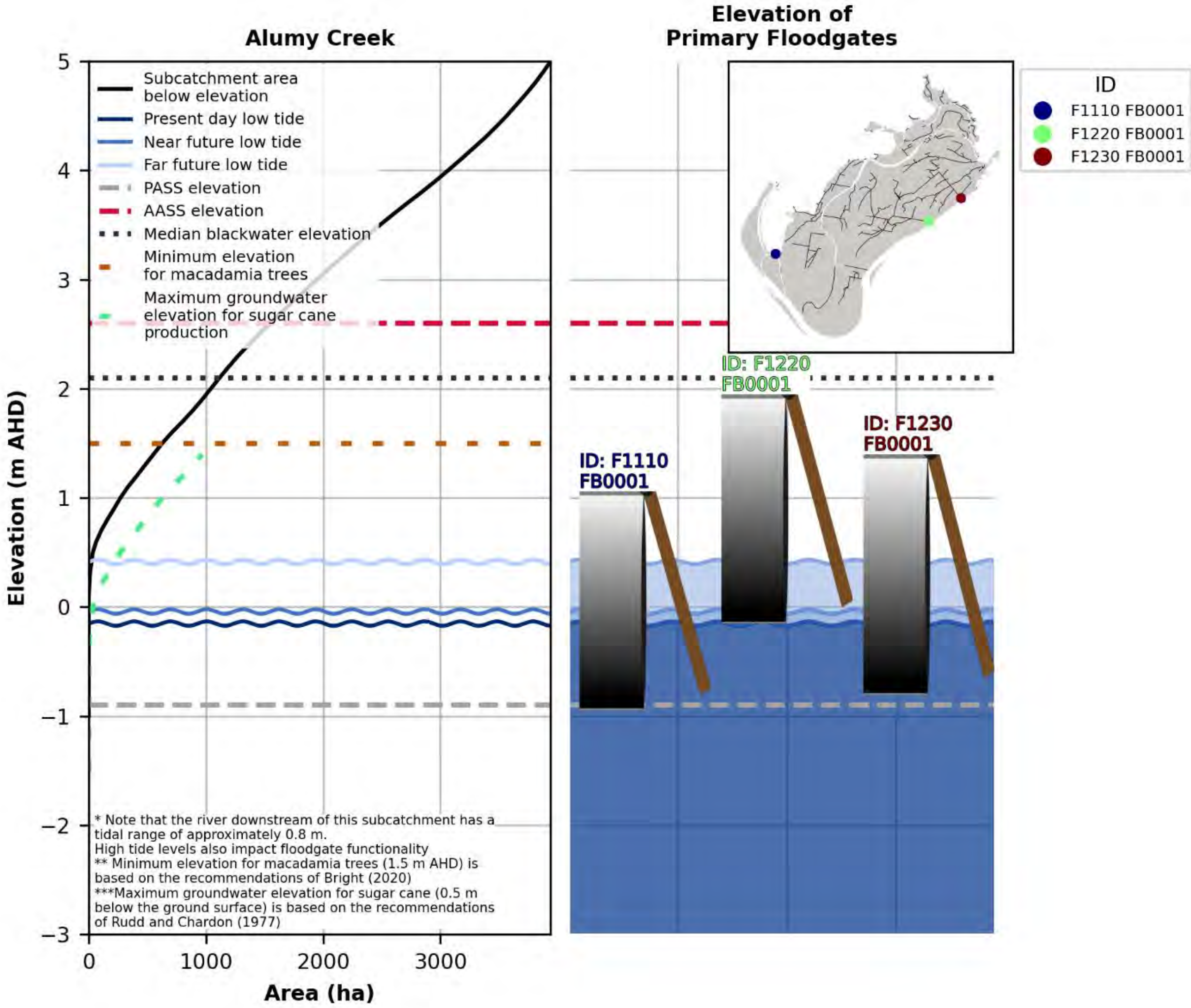

Figure 8-88: Primary floodgates and key floodplain elevations – Alumy Creek subcatchment

8.16.4 Management options

Short-term management options

Investigations should be completed to determine whether major infrastructure could be modified to allow flushing through the installation of auto-tidal buoyancy gates without impacting upstream land use. While this subcatchment was assessed as a lower risk of acid drainage in the context of the broader Clarence River floodplain, soil pH of 4.5 was observed at one location (profile CP 20, more details available in Appendix D) and improved flushing will help to mitigate the impacts of acidic soils. Additional investigation of soil acidity would improve the understanding of the distribution of ASS within the subcatchment.

Long-term management options

In the long term, low-lying areas may be impacted by reduced drainage which may influence land uses in lower areas. If present day land uses are impacted, the restoration of natural freshwater backswamp hydrology should be considered in the lowest lying areas. This would encourage freshwater retention and water tolerant vegetation which would reduce the risk of blackwater generation from this subcatchment. This would require redesigning and reshaping the drainage system upstream to reduce connectivity with the Clarence River and other creek systems. Water could be strategically held back in the low areas for an extended period of time to mitigate the impact of blackwater on the Clarence River after flood events. Any changes to the drainage system will need to be completed with consideration of the potential social and economic impacts on local landholders.

A summary of the recommended management options for the Alumy Creek subcatchment is provided in Table 8-21.

Table 8-21: Summary of management options for Alumy Creek

		Effectiveness at improving:		
Timeframe	**Strategy**	**Wetland habitat and fish passage**	**Impacts of ASS**	**Impacts of blackwater**
Short-term	Floodgate modifications	Moderate	Small	Negligible
Long-term	Localised restoration of backswamp	None	Moderate	Moderate

8.17 Southgate subcatchment

Acid priority rank:	**15**
Blackwater priority rank:	**12**
Infrastructure	
Approximate waterway length (km)	28
# Privately owned end of system structures	2
# Publicly owned end of system structures	5
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID):	F-1310-FP-0001, F-1730-FP-0001, F-1740-FB-0001
Elevations	
Invert of primary floodplain infrastructure (m AHD)	-1 to -0.3
Approximate AASS elevation (m AHD)	N/A
Approximate PASS elevation (m AHD)	-0.1
Median blackwater elevation (m AHD)	1.8
Present day low water level (m AHD)	-0.1
Near future low water level (m AHD)	0.0
Far future low level (m AHD)	0.4
Proximity to sensitive receivers	
Oyster leases (km)	41.2
Saltmarsh (km)	14.2
Seagrass (km)	32.4
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	2.5
Land use	
Total floodplain area (ha)	1,132
Classified as conservation and minimal use (ha (%))	0 (0%)
Classified as grazing (ha (%))	884 (78%)
Classified as forestry (ha (%))	2 (0%)
Classified as sugar cane (ha (%))	0 (0%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	148 (13%)
Classified as urban/industrial/services (ha (%))	15 (1%)
Classified as marsh/wetland (ha (%))	5 (0%)
Other (ha (%))	77 (7%)
Land values	
Estimated total primary production value ($/year)	$370,000
Average land value above 1.8 m AHD ($/ha)	$10,200
Average land value below 1.8 m AHD ($/ha)	$8,300

8.17.1 Site description

The Southgate subcatchment is on the right bank of the Clarence River, shown in Figure 8-89 and is predominantly used for grazing. The subcatchment is less than 1,000 ha, and has a series of natural levees and small backswamps. The topography and drainage in the Southgate subcatchment is shown in Figure 8-90.

The Southgate subcatchment is east of the Alumy Creek subcatchment and includes the Southgate Creek waterway which also drains Alumy Creek. The drainage history of Alumy Creek is detailed in Section 8.16.1, which includes the Alumy Creek Weir located in Southgate Creek.

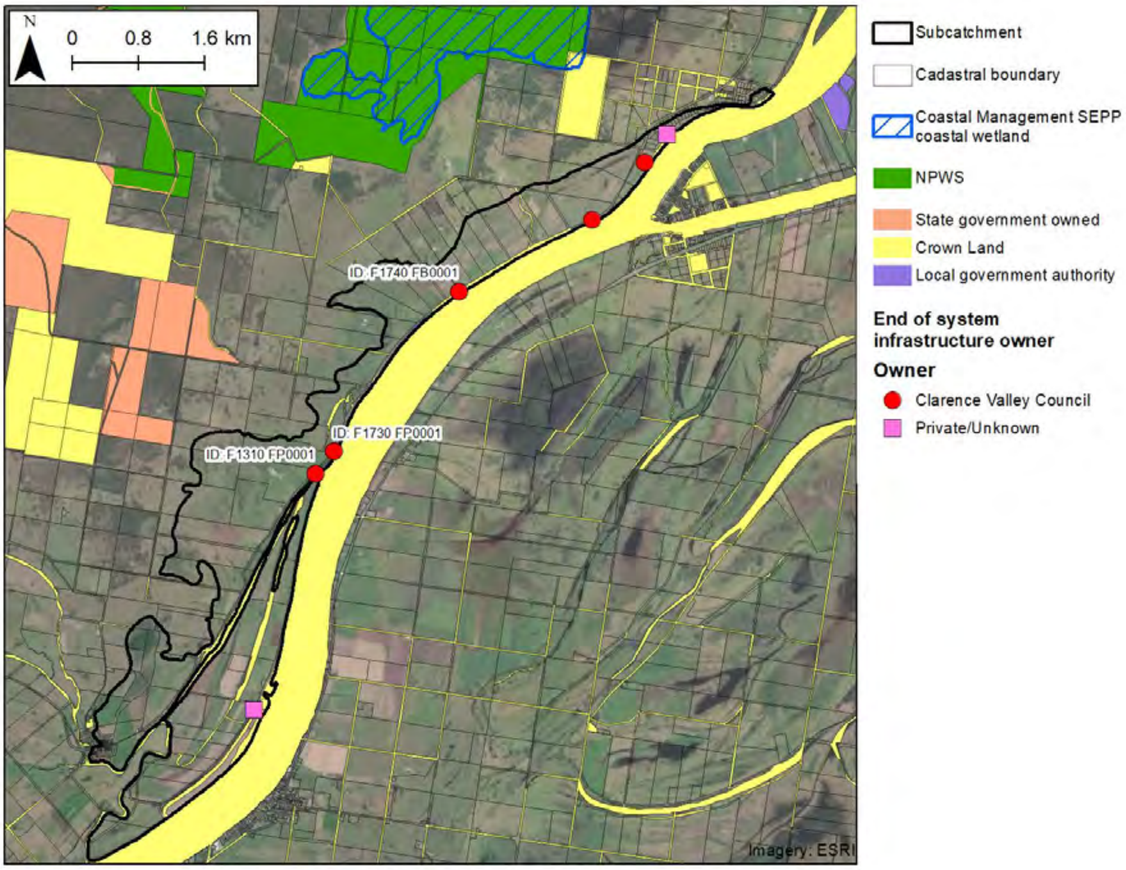

Figure 8-89: Southgate subcatchment - land and end of system infrastructure tenure

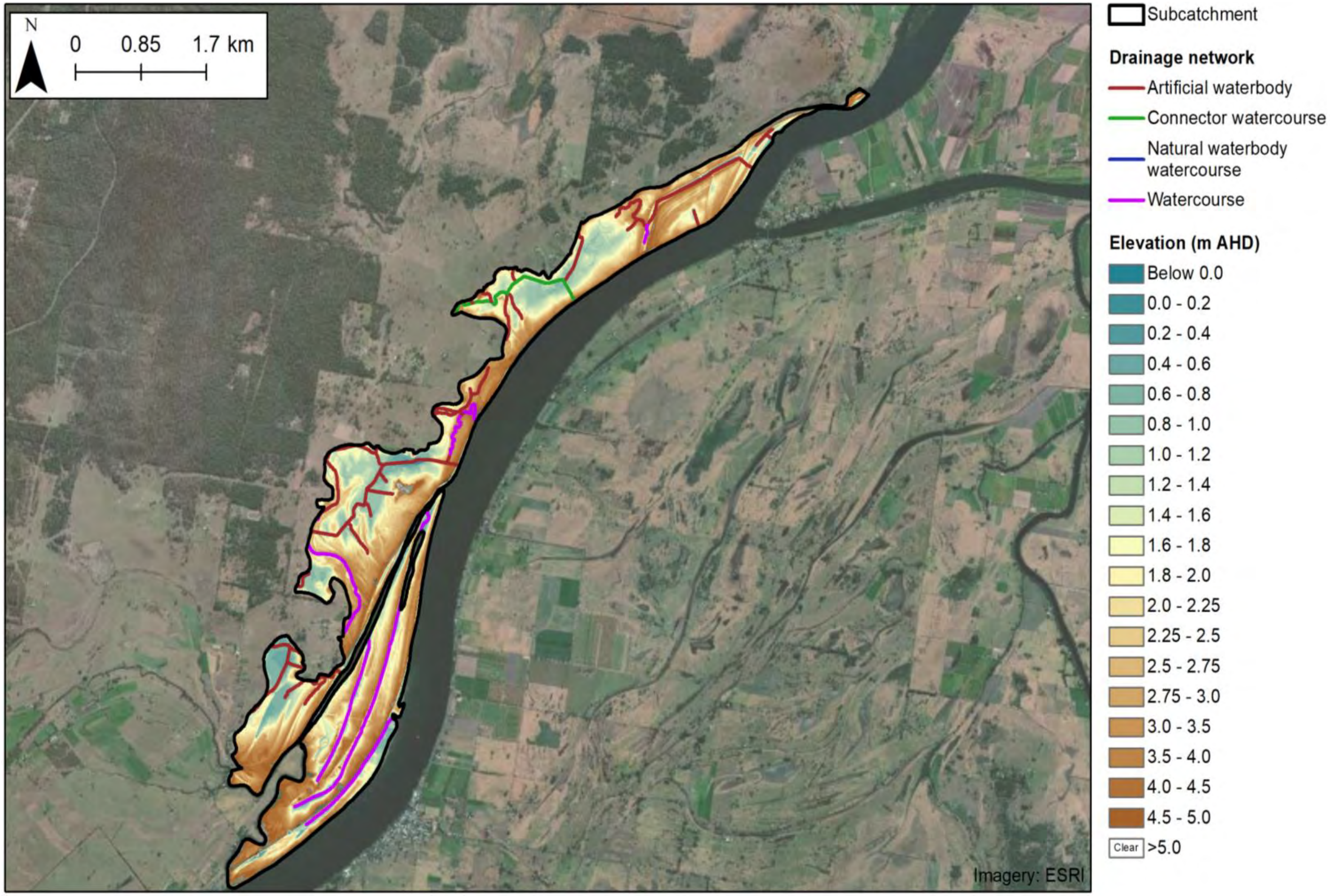

Figure 8-90: Southgate subcatchment elevation and drainage network

8.17.2 History of remediation

One (1) of the floodgates in the Southgate subcatchment has been modified to allow some tidal flushing, on the eastern side of the subcatchment, shown Figure 8-91. This floodgate (floodgate ID F-1750-FT-0001) has had a buoyancy gate and lifting system fitted to allow managed tidal flushing.

Note that the Alumy Creek Weir was discussed in the Alumy Creek subcatchment.

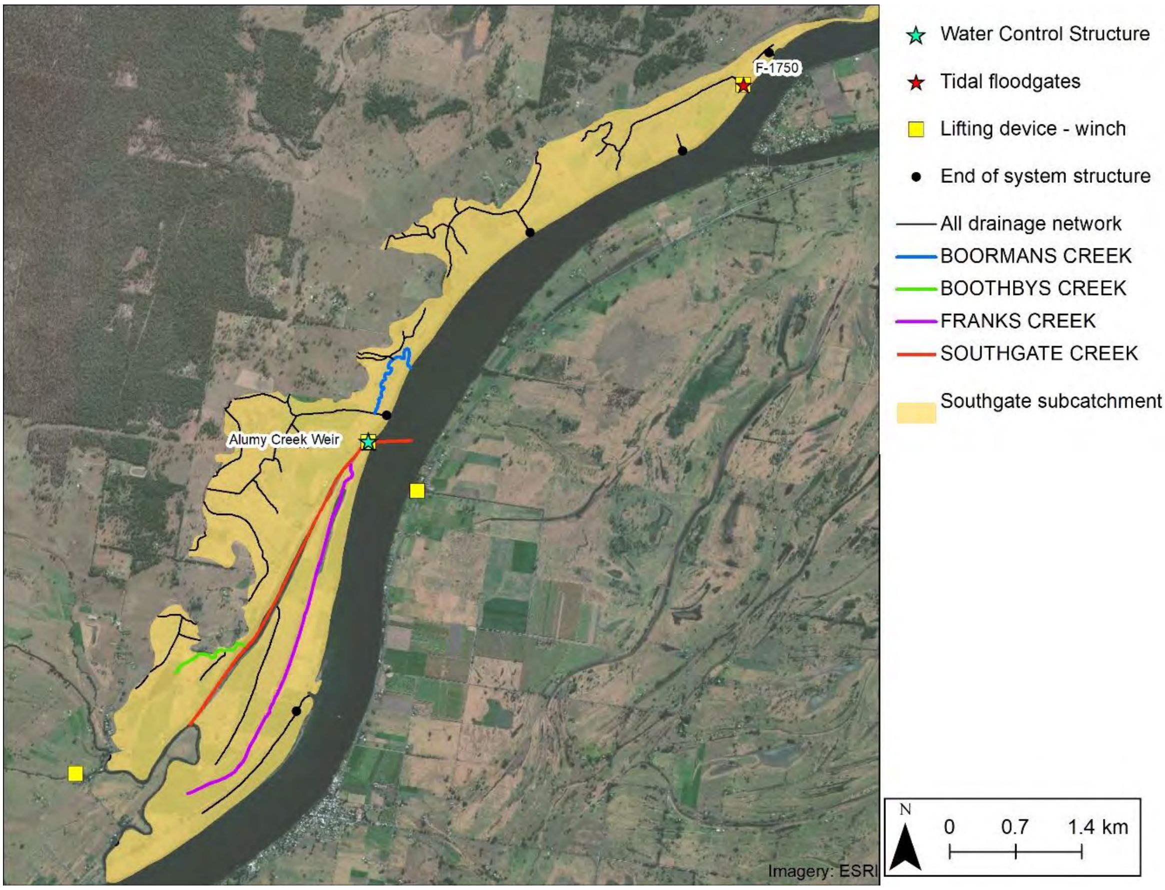

Figure 8-91: Southgate subcatchment including previous remediation actions

8.17.3 Floodplain drainage - sea level rise vulnerability

The sea level rise vulnerability of the Southgate subcatchment is summarised in Figure 8-92, while the elevation of primary floodgates is compared to key floodplain elevations in Figure 8-93. Floodgate ID F-1730-FP-0001, which drains the lowest area in the subcatchment is classified as "Moderately vulnerable" under the present day scenario, and is "Most vulnerable" under the far future sea level rise scenario. The floodplain behind this floodgate is also likely to be increasingly impacted by reduced drainage as sea level rise occurs. This may impact the productivity of current land uses. Similarly, other low areas (particularly below +0.8 m AHD) may also be impacted by reduced drainage. Secondary floodgates F-1750-FP-0001 and UNK173 were also classified as 'Most vulnerable' in the far future.

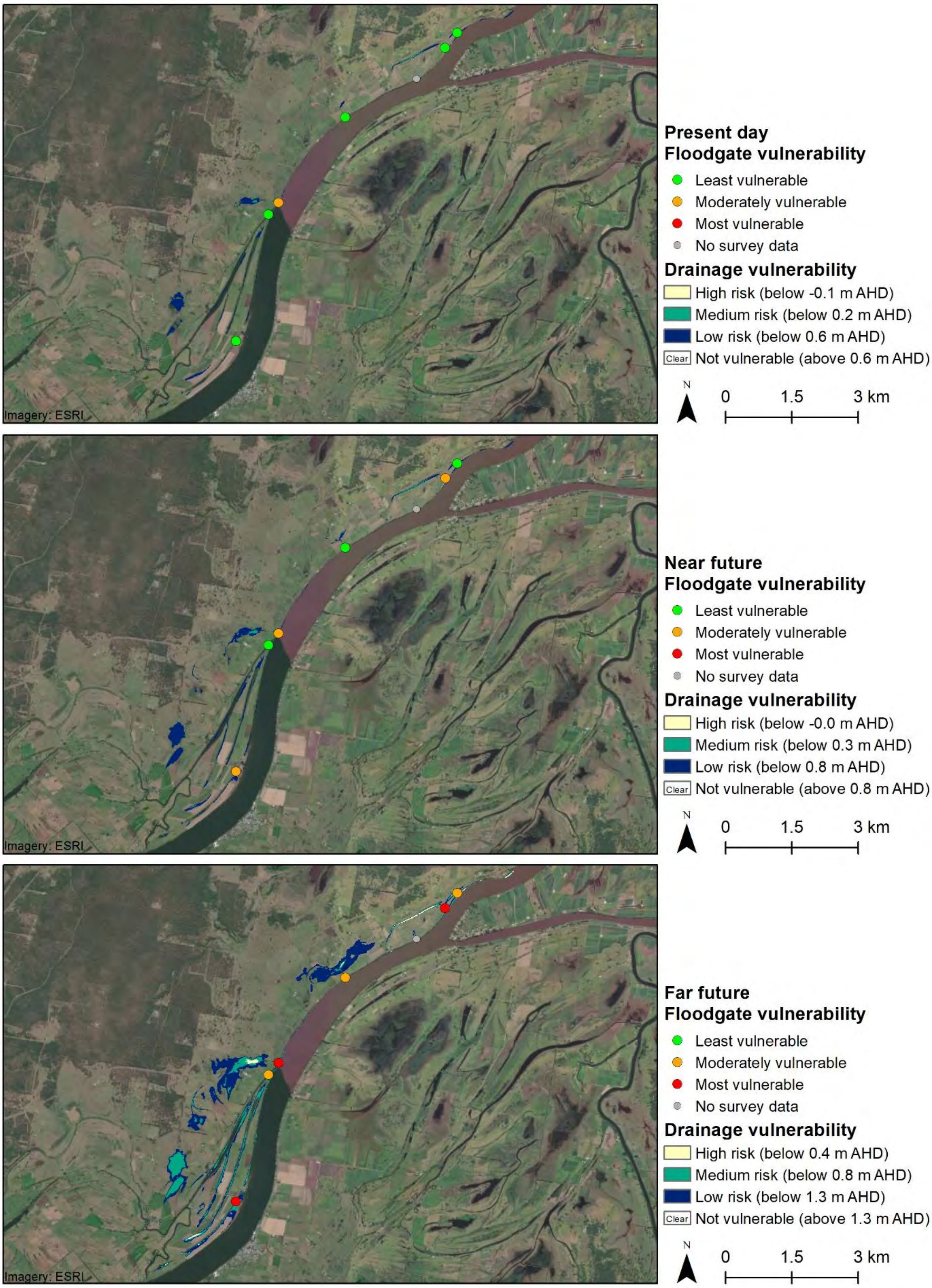

Figure 8-92: Sea level rise drainage vulnerability – Southgate subcatchment

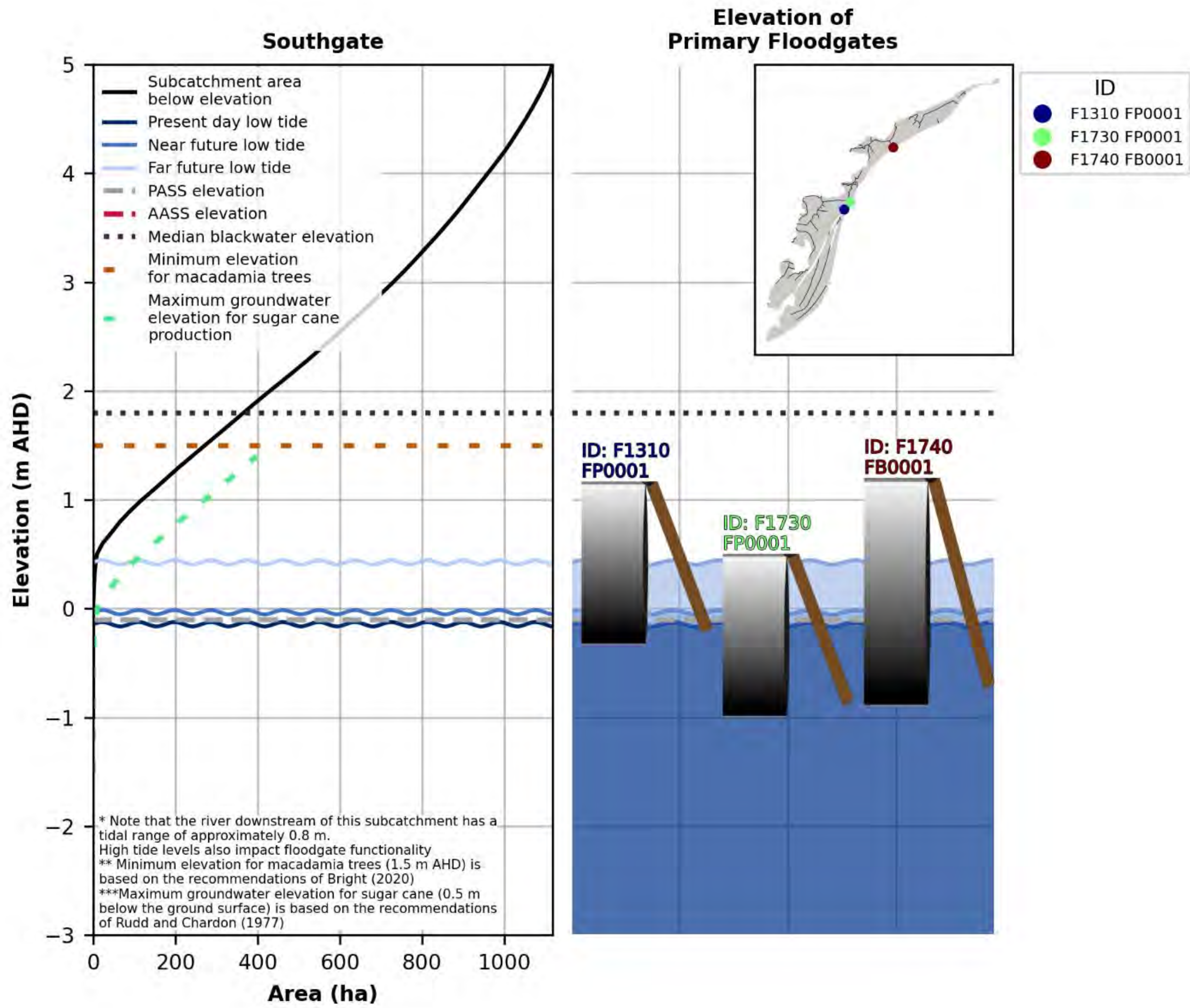

Figure 8-93: Primary floodgates and key floodplain elevations – Southgate subcatchment

8.17.4 Management options

Short-term management options

It is recommended that any un-modified floodgates be considered to allow additional tidal flushing. While this subcatchment was assessed as low risk for ASS, and estuarine salinity is generally low except during prolonged dry periods (Manly Hydraulics Laboratory, 2016), tidal flushing may facilitate improvements in general water quality and aquatic connectivity within the drainage system.

Floodgate ID F-1730-FP-0001 was assessed as ‘Moderate Priority’ for remediation by Williams (2000) as it drains an area that would have historically been a 2 km^2 wetland and acid scalds had been observed. Williams (2000) suggested two potential management options:

1. Install two mini sluice gates to allow limited flushing through the floodgate (note that this could also be auto-tidal buoyancy gates); and
2. Install a winch on the floodgate and a dropboard weir structure upstream to retain freshwater on the backswamp area.

At the time, it was noted that the private landholder was not interested in active management of the floodgate (Williams, 2000). However, these options should be investigated to improve water quality and fish passage in this area. Such works would only be feasible if the local landholder was interested in changes in land management on their property.

Long-term management options

In the longer term, reduced drainage may impact the land uses in the low areas. If freshwater retention has not been encouraged in the wetland area upstream of floodgate ID F-1730-FP-0001, this should be re-investigated if present land uses cannot persist. This will encourage water tolerant vegetation and reduce the risk of blackwater generation in the area.

A summary of the recommended management options for the Southgate subcatchment is provided in Table 8-22.

Table 8-22: Summary of management options for Southgate

		Effectiveness at improving:		
Timeframe	**Strategy**	**Wetland habitat and fish passage**	**Impacts of ASS**	**Impacts of blackwater**
Short-term	Floodgate modifications	Moderate	Small	Negligible
Long-term	Localised restoration of backswamp	None	Small	Small

8.18 The Freshwater subcatchment

Acid priority rank:	**16**
Blackwater priority rank:	**16**
Infrastructure	
Approximate waterway length (km)	5
# Privately owned end of system structures	0
# Publicly owned end of system structures	9
# End of system structures within coastal wetlands	0
# Publicly owned end of system structures within coastal wetlands	0
Primary floodplain infrastructure (ID)	N/A
Elevations	
Invert of primary floodplain infrastructure (m AHD)	N/A
Approximate AASS elevation (m AHD)	N/A
Approximate PASS elevation (m AHD)	N/A
Median blackwater elevation (m AHD)	0.9
Present day low water level (m AHD)	-0.4
Near future low water level (m AHD)	-0.3
Far future low level (m AHD)	0.2
Proximity to sensitive receivers	
Oyster leases (km)	2.0
Saltmarsh (km)	Within subcatchment
Seagrass (km)	Within subcatchment
Mangroves (km)	Within subcatchment
Coastal Management SEPP coastal wetlands (km)	Within subcatchment
Land use	
Total floodplain area (ha)	2,912
Classified as conservation and minimal use (ha (%))	2,593 (89%)
Classified as grazing (ha (%))	17 (1%)
Classified as forestry (ha (%))	0 (0%)
Classified as sugar cane (ha (%))	14 (1%)
Classified as horticulture (ha (%))	0 (0%)
Classified as other cropping (ha (%))	6 (0%)
Classified as urban/industrial/services (ha (%))	156 (5%)
Classified as marsh/wetland (ha (%))	1 (0%)
Other (ha (%))	123 (4%)
Land values	
Estimated total primary production value ($/year)	$52,000
Average land value above 0.9 m AHD ($/ha)	$21,500
Average land value below 0.9 m AHD ($/ha)	$800

8.18.1 Site description

The Freshwater subcatchment is in the lower Clarence River, near the towns of Woombah and Iluka. The majority of the subcatchment is within the Bundjalung National Park, shown in Figure 8-94 and there is only very minimal agricultural land use in the subcatchment. The drainage infrastructure in this subcatchment services the township of Iluka, and a small area on the western edge of the catchment. There is limited artificial drainage within the National Park. The topography of the subcatchment is shown in Figure 8-95.

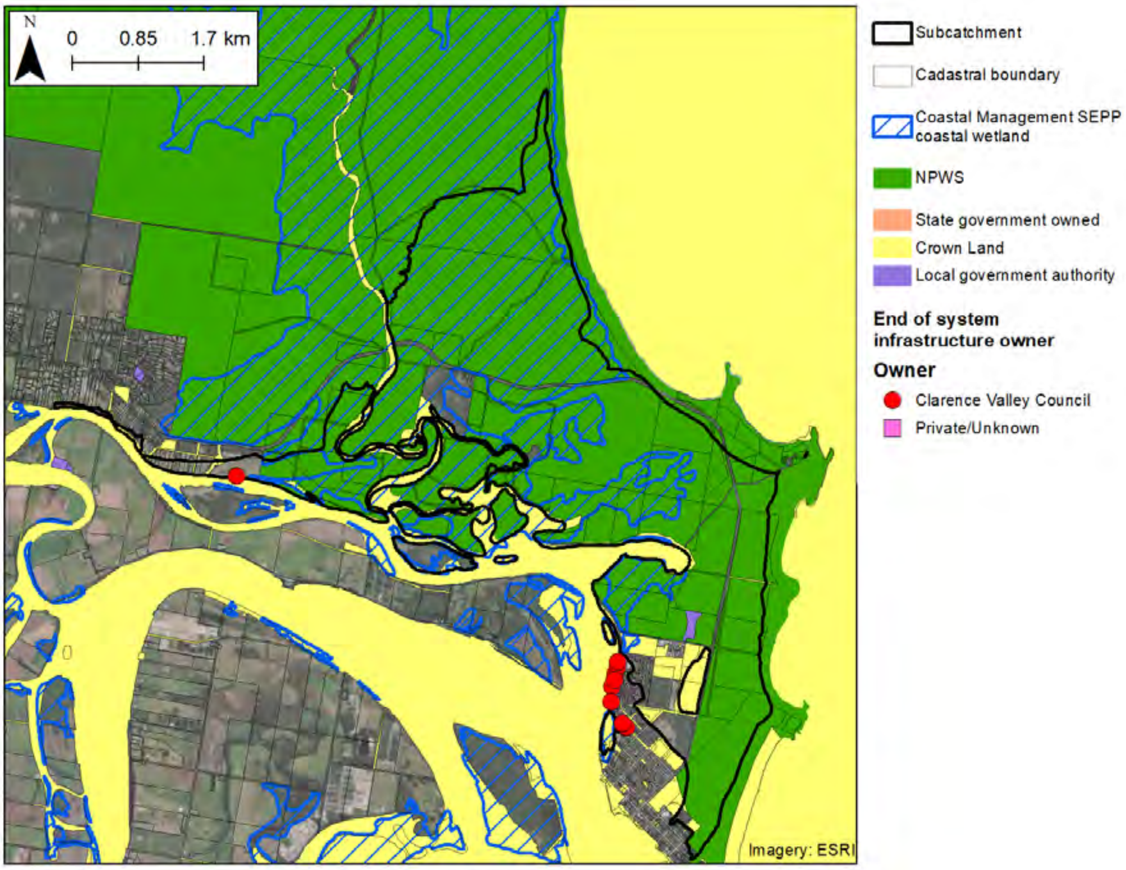

Figure 8-94: The Freshwater subcatchment - land and end of system infrastructure tenure

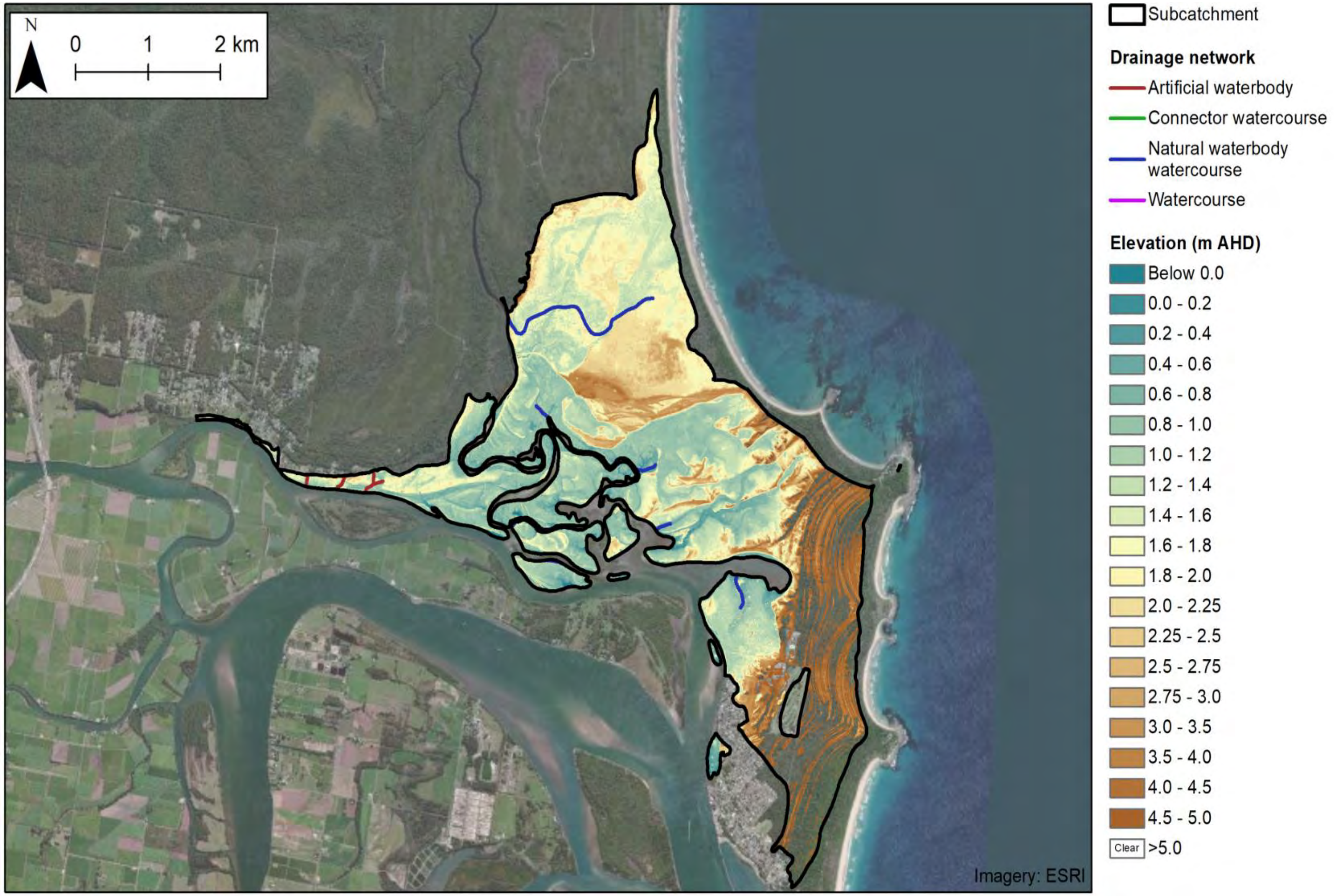

Figure 8-95: The Freshwater subcatchment elevation and drainage network

8.18.2 History of remediation

As the majority of The Freshwater subcatchment is within the Bundjalung National Park, limited development has occurred in this subcatchment and no previous remediation has been identified.

8.18.3 Floodplain drainage - sea level rise vulnerability

Figure 8-96 summarises the climate change vulnerability for The Freshwater subcatchment. The low areas in this subcatchment are tidal and are not behind floodgate infrastructure. The changes in sea levels as a result of sea level rise will likely increase the intertidal area in this subcatchment and cause a change in vegetation.

The effects of sea level rise on flood impacts in Iluka have not been considered in this study.

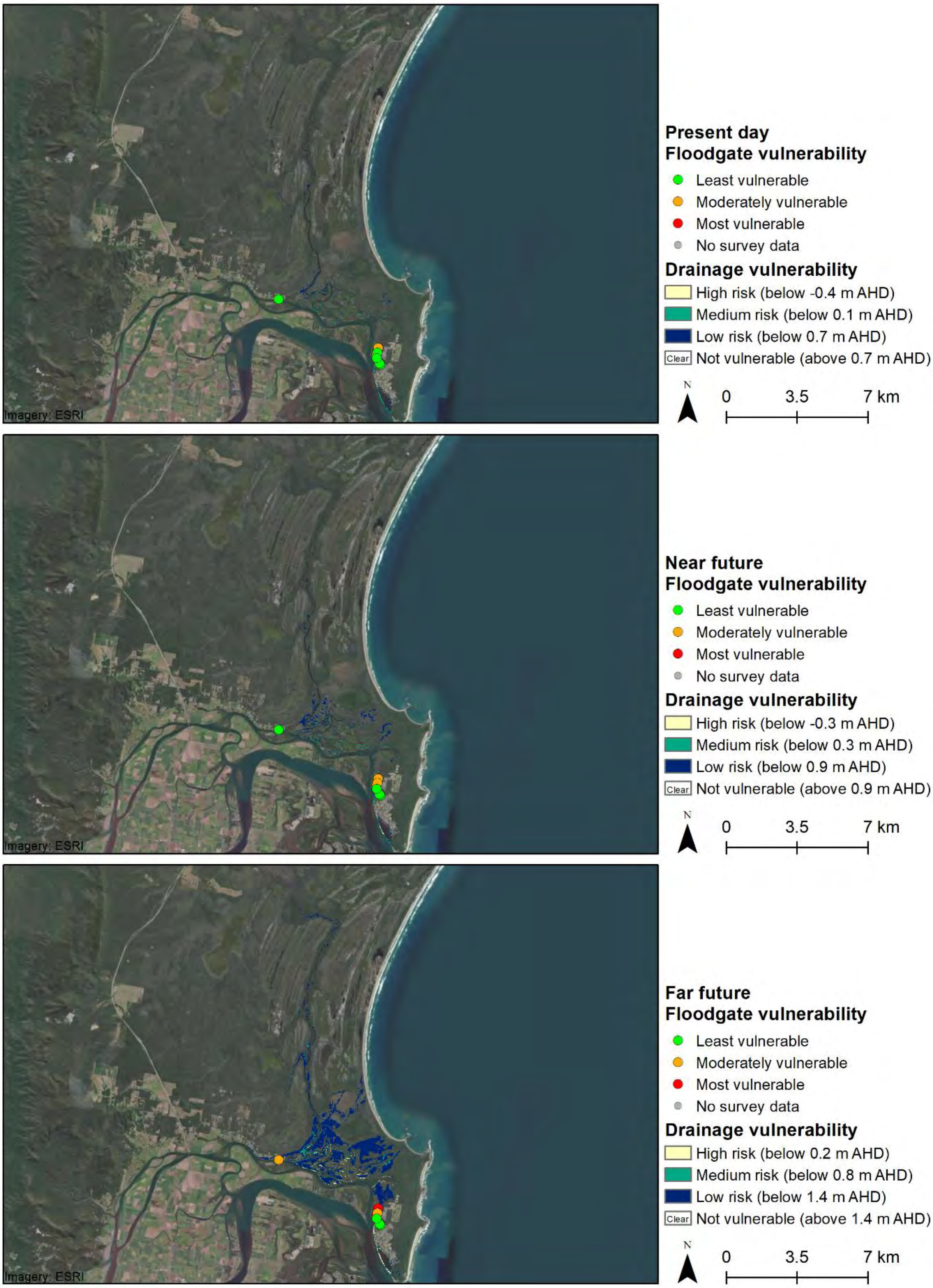

Figure 8-96: Sea level rise drainage vulnerability – The Freshwater subcatchment

8.18.4 Management options

Short-term management options

The vast majority of The Freshwater subcatchment is within the Bundjalung National Park and has not been modified. No change in land management is required to further address blackwater or acid discharges, although on-going support for NPWS is recommended.

Long-term management options

Long-term, urban growth and development pressure in the town of Iluka should be managed with development controls to prevent unnecessary drainage in this subcatchment. Otherwise, ongoing management of the National Park should continue to be supported.

9 Outcomes and recommendations

9.1 Preamble

The objective of the Coastal Floodplain Prioritisation Study was to provide a roadmap for the strategic management of acid sulfate soils (ASS) and low oxygen blackwater runoff from seven (7) major coastal floodplains in NSW, to improve the water quality and overall health of the marine estate. This has been achieved through the development and application of an evidence based and data driven multi-criteria assessment involving:

- Application of a prioritisation methodology to rank 16 subcatchments on the Clarence River floodplain with regard to their contribution to acid and blackwater generation and the risk they pose to the health of the marine estate;
- Suggested management options for individual subcatchments outlining potential strategies for on-ground works to improve water quality; and
- Collation of catchment specific data relevant to the implementation of management options.

This approach has identified high-priority subcatchments within the Clarence River coastal floodplain system to allow targeted floodplain management to improve water quality. The outcomes of the subcatchment prioritisation and supporting information, provide an objectively prioritised list of 16 floodplain subcatchments with a roadmap on how to achieve water quality improvements across the Clarence River coastal floodplain. This can be used by floodplain managers to directly reduce the environmental threats posed to the marine estate by diffuse runoff associated with acid sulfate soil discharges and blackwater generation, and will allow for the subsequent social, cultural and economic benefits to be fully realised.

9.2 Outcomes

The multi-criteria prioritisation methodology was applied to rank the 16 subcatchment drainage areas of the Clarence River floodplain with respect to the risk they pose to the marine estate due to poor water quality associated with ASS and blackwater runoff. The prioritisation methodology utilised a data driven approach to objectively rank the subcatchments. It is strongly recommended that this data, as well as additional data collected into the future be collated into an estuary wide database that is readily accessible to land managers. Data considered during this analysis included:

- Topography;
- Groundwater potential flow rate (i.e. hydraulic conductivity);
- Floodplain drainage;
- Catchment hydrology;
- Soil parameters including acid concentration;
- Land use; and
- Estuarine and tidal dynamics.

The acid prioritisation assessment considers the volume of acid stored within a floodplain and the potential for it to be transported to an estuary, to objectively rank floodplain subcatchments from highest to lowest priority with respect to the risk due to acid discharges. Within the Clarence River floodplain, the highest five (5) priority subcatchments for acid drainage: Sportsmans Creek (1), Swan Creek (2), Gulmarrad/East Woodford Island (3), Shark Creek (4) and Taloumbi/Palmers Channel (5) were estimated to contribute over 80% of the total acid risk to the estuary. The Sportsmans Creek subcatchment was estimated to individually be the source of 35% of acid risk to the estuary. High risk acid subcatchments were identified in the upper, middle, and lower reaches of the estuary, indicating that acid discharges from the floodplain have the potential to impact all areas of the Clarence River estuary (Table 9-1).

Table 9-1: Clarence River floodplain subcatchment priority ranking

Floodplain subcatchment	Acid Rank	Blackwater Rank
Sportsmans Creek	1	2
Swan Creek	2	3
Gulmarrad/East Woodford Island	3	10
Shark Creek	4	5
Taloumbi/Palmers Channel	5	4
Coldstream River	6	1
Mororo/Ashby	7	15
The Broadwater	8	8
Maclean	9	13
Harwood/Chatsworth/Goodwood/Warregah Islands	10	9
Palmers Island/Micalo Island/Yamba	11	14
South Grafton	12	11
West Woodford Island	13	6
Alumy Creek	14	7
Southgate	15	12
The Freshwater	16	16

Application of the blackwater prioritisation methodology identified areas that are most likely to contribute to blackwater generation due to:

(i) Susceptibility to prolonged floodplain inundation following flood events; and
(ii) Distribution of water tolerant (or intolerant) vegetation across the floodplain.

This data was used to objectively rank subcatchments from highest to lowest based on the risk they pose to the marine estate in terms of exporting poor quality low oxygen blackwater to the estuary. This assessment identified that the Coldstream River subcatchment, ranked first in the blackwater prioritisation, accounts for more than 25% of the overall blackwater generation potential in the Clarence River floodplain. The highest three (3) ranked subcatchments (Coldstream River, Sportsmans Creek and Swan Creek), collectively account for over 50% of the total blackwater risk (Table 9-1). While the highest three (3) ranked subcatchments for blackwater generation are located in the mid-to-upper estuary, blackwater generation potential exists throughout the Clarence River floodplain.

Following the prioritisation of subcatchments, management options have been suggested to guide the potential on-ground actions that could be completed to address the impacts of poor water quality associated with ASS and blackwater runoff. Management options have been proposed for the short-term, assuming existing land use practices will remain unchanged across the floodplain, and the long-term, where environmental stressors on subcatchments such as sea level rise may require strategic changes to floodplain management. Any changes in management of these areas will require consultation with local landholders and a comprehensive understanding of, and a plan to mitigate, the social and economic impacts of changes in land management on the community. Management options have been suggested for individual subcatchments taking into consideration:

- Priority ranking for acid and blackwater;
- Proximity to sensitive receivers;
- Condition of existing floodplain infrastructure;
- Historical remediation works;
- Estuarine influence on the floodplain (e.g. tide and salinity levels);
- Current and future land uses;
- Current and future land values; and
- The relative costs and benefits of remediating the floodplain.

Management options have also considered the impacts that sea level rise will have on floodplain drainage. To complete this assessment, detailed numerical modelling of the Clarence River estuary was completed to assess the vulnerability of floodplain drainage to sea level rise. Historical (~1960s), present day (2020), near future (~2050) and far future (~2100) sea levels were modelled and compared to floodgate infrastructure geometry and floodplain topography to assess floodplain vulnerability to reduced drainage under future sea levels. The assessment identified floodplain infrastructure and areas potentially vulnerable to sea level rise as summarised in Table 9-2. This information was then used to inform the development of management options which are designed to guide the future strategy adopted by floodplain managers to improve the health of the marine estate.

Table 9-2: Clarence River floodplain vulnerability under sea level rise

Vulnerability Status	Historic Scenario (HS) ~1960	Present Day (PD) 2020	Near Future (NF) ~2050	Far Future (FF) ~2100
Floodgates (number of)				
Least vulnerable floodgates	290	262	227	132
Moderately vulnerable floodgates	66	86	101	78
Most vulnerable floodgates	19	27	47	165
Floodplain Area (hectares)				
Low vulnerability area	8,426	10,461	11,976	19,008
Moderate vulnerability area	295	1,132	3,231	8,546
High vulnerability area	3	14	77	8,163

The management options suggested as part of this study are high level and intended to guide the overall strategy that should be considered by floodplain managers when addressing sources of diffuse poor water quality. It is acknowledged that further detailed on-ground investigations are required prior to the commitment to any on-ground actions, including consideration of impacts on local landholders. While this is not specifically addressed as part of this study, a range of factors which influence implementation have been collated to assist floodplain managers during the detailed design of works to improve water quality. Implementation factors to be considered during detailed design and changes to existing management include:

- Waterway status (natural or artificial);
- Infrastructure and land tenure;
- Land value (including production, purchase and remediation values);
- Future land use planning;
- Location of sensitive receivers; and
- Location of heritage items.

Outcomes from the Clarence River Floodplain Prioritisation Study provide a roadmap for floodplain land managers to directly improve poor water quality associated with diffuse runoff caused by acid and blackwater generation on the coastal floodplain. Specifically, this study has:

1. Ranked subcatchments on the basis of the risk they pose to the marine estate in terms of poor water quality resulting from ASS and blackwater runoff;
2. Suggested potential management options that describe the overall strategy for floodplain management to improve water quality; and
3. Identified and collated key datasets that will be valuable for floodplain management.

9.3 Conclusions

Substantial efforts have been made in the Clarence River estuary to address poor water quality from acid sulfate soils and blackwater, mainly led by Clarence Valley Council (primarily through the Clarence Floodplain Project) with the support of local landholders. Notably, a large number of major floodplain end-of-system infrastructure has been modified to allow controlled flushing (e.g. sluice gates, auto-tidal gates and winches) and improved waterway connectivity with the estuary. Numerous landholders have co-operated with trials of wet pasture management, and drainage management to reduce acid drainage from the floodplain, which has generally been successful at improving water quality on a paddock scale. These remediation efforts should be encouraged and commended. However, the scale of on-going large event-based floodplain discharges of blackwater and acid, particularly from Sportsman Creek, Swan Creek and the Coldstream River can only be substantially addressed through broadscale changes to land use and a restoration of natural floodplain hydrology. Broadscale management changes throughout the floodplain will need to consider, and have a plan to mitigate potential social, cultural, and economic impacts to local landholders.

Sufficient scientific and technical understanding exists to identify, address, and mitigate many of the environmental issues that coastal floodplains and estuaries face, both now and into the future. Particularly as sea level rise impacts drainage and agricultural land uses in the lowest lying areas of the floodplain, a catchment wide strategy needs to be established to assist the community adapting to a changing environment and supporting a future that is environmentally and economically sustainable. This will require cooperation between all levels of government, the local community, and industry, to ensure long-term management of coastal floodplains and estuaries is proactive and adaptive. The implementation of scientific knowledge and technical solutions is impeded by political, social, and economic barriers, which will need to be overcome if our estuaries are to thrive into the future.

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